HT-ATES feasibility for TRIAS Westland

case study

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Technical References

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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
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Document history

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Abstract

Introduction

In this study, the feasibility of HT-ATES for the TRIAS Westland project is assessed, and the site of TRIAS Westland is used to develop and demonstrate a cost-effective method to identify and characterize suitable aquifers for HT-ATES by combining the drilling of a geothermal well with logging and screening of potential HT-ATES aquifers. This is promising because many greenhouses will decarbonize their heat supply by utilizing geothermal heat production. This method is applied and used to assess the HT-ATES feasibility for the site of TRIAS Westland. Hence, the goal of this work is twofold:

1. Identify the (technical, economic, legal, environmental) feasibility of HT-ATES in the TRIAS Westland project.
2. Develop a (combination of) method(s) for logging and screening of possible suitable layers while drilling of a geothermal wells.

1. HT-ATES is feasible at TRIAS Westland

The technical and financial analysis shows that there is potential to cost-efficiently increase sustainable heat delivery from the geothermal wells of the TRIAS Westland site by applying an HT-ATES. The yearly total costs of the HT-ATES are considerably smaller than they would be if the same amount of heat would be delivered by gas fired boilers. The results of this feasibility study are summarised using the ULTIMATE KPI's in the table below.

Overview of the ULTIMATE KPI's and the scales of the TRIAS Westland project.

Objective	How it will be measured/determined?	Scale: full-scale
HT Aquifer thermal energy storage and recovery	Heat recovery factor [-], Delivered heat cost [€/GJ], CO_2 reduction [t/a]	65 to 80 % 15 to 20 €/GJ 3 to 4 kton CO_2/y
Showing the success of the implemented circular economy systems	Substitution of fossil fuels by green energy [%]	5 to 6%*

*For the TRIAS Westland site, the heat storage and fossil substitution is 75-60 TJ. Because the system is very large (>1300 TJ) and has a high base-load heat demand, the contribution of HT-ATES to the total is limited. In other supply-demand conditions HT-ATES systems are more likely to facilitates 20 to 30% of the total heat demand.

The deepest aquifer in Maassluis formation is very suitable for installation of HT-ATES wells. The top of the projected aquifer is at 210 m depth and the thickness is around 30m. The additional screening and logging proved to be key to identify available well screen depths.

HT-ATES requires a permit from the Province. However, no standard policy framework for permitting of these systems exists. The issuing of a permit requires a dedicated decision of the 'Gedeputeerde Staten' of the province.

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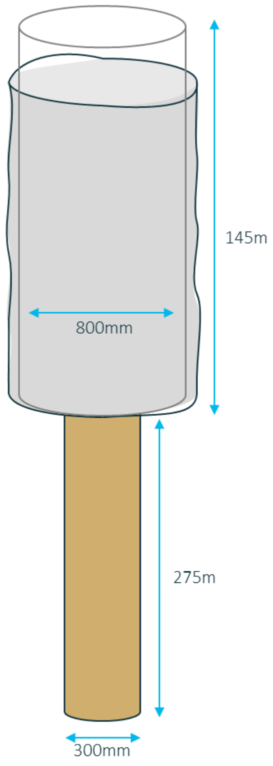
2. Methods for HT-ATES feasibility screening, while drilling for deeper aquifers
Various HT-ATES feasibility studies have shown that detailed knowledge on the composition of the subsurface is key to correctly assess HT-ATES feasibility. While drilling a deeper, e.g. geothermal, well, the overlying potential layers for HT-ATES are penetrated. This creates the opportunity to obtain insight in these layers. Logging/screening these shallow layers while targeting a (much) deeper aquifer, is a cost effective method to gather valuable information to reduce uncertainty for the application of HT-ATES.

In this study it was demonstrated that data acquisition for shallow layers, during drilling activities for geothermal systems, can cost effectively and successfully be implemented. The obtained data provided great insight in potential layers at reasonable costs. The approach followed in this study can easily be applied in other projects.

The approach consisted of deepening the conductor drilling of the geothermal well, which are usually around 100m depth in NL, schematically represented in the figure below. Those conductors are generally made by smaller rigs. This has 2 main advantages:

1. The daily cost of such rigs is much lower than for the large rig drilling to several km depth. So the costs of extra time needed to core/log the shallow subsurface is limited.
2. Such smaller rigs allow for reverse circulation flush drilling through the more shallow layers, providing very accurate cutting samples along the borehole depth.



Schematic representation of the deepening drilling as carried out at the TRIAS Westland site.

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1. Introduction

1.1. HT-ATES in the ULTIMATE project

The ULTIMATE project aims to demonstrate the feasibility of innovative technological solutions in order to foster circular economy in the water sector. Therefore, the symbiosis between the industrial sector and service providers is used for a mutual advantage of both via a synergetic cooperation. In 9 symbioses demonstrated at 9 case studies, the water, material and energy cycles are closed also, considering the nexus between the three cycles. Because the ULTIMATE case for utilization of residual heat from the chemical complex at Nieuw Prinsenland is stopped, there is no longer the possibility to include the energy part at this site. Therefore, the demonstration of the high-temperature aquifer thermal energy storage (HT-ATES) system is carried out at other greenhouses in the Westland greenhouse-area at the geothermal well of TRIAS Westland. To demonstrate the HT-ATES solution for greenhouses, the potential for this technology is investigated.

1.2. Goal

In this study, the site of TRIAS Westland is used to develop and demonstrate a cost-effective method to identify and characterize suitable aquifers for HT-ATES, by combining the drilling of a geothermal well with logging and screening of potential HT-ATES aquifers.

- This is needed because for HT-ATES often deeper and less familiar aquifers are targeted and more than for normal/LT-ATES the detailed characteristics are key to identify feasibility.
- This is promising because many greenhouses will decarbonize their heat supply by utilizing geothermal heat production. This information is then used to assess the HT-ATES feasibility for that site.

To demonstrate this method, this task includes a feasibility study of HT-ATES for the TRIAS Westland project. Hence, the goal of this work is two folded:

1. Identify the (technical, economic, legal, environmental) feasibility of HT-ATES for the TRIAS Westland project. This is assessed together with the site developer/owner (HVC). This includes:
    a. Identification of the required HT-ATES characteristics.
    b. Identification of most suitable layers and establishment of a preliminary design of the wells.
    c. Cost-benefit and legal analysis
2. Develop a (combination of) method(s) for logging and screening of possible suitable layers while drilling of a geothermal wells.

The development of the screening method is a key element in this study, but in an HT-ATES feasibility study it is one of the many aspects that need to be evaluated. This report is structured around the feasibility analysis, in the relevant sections the screening method is discussed, not in a separate section/chapter.

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1.3. Background HT-ATES & geothermal

In general, geothermal systems produce excess heat in summer, while capacity in winter is not enough to meet peak demand. By storing the produced heat in summer and deliver this in winter during peak demand increases utilization of the geothermal heat and reduction of emissions. Hence, the combination of a geothermal system and HT-ATES allows for optimal utilization of the available heat and also cost effectively and carbon free supply of peak demand, Figure 1. Because HT-ATES is not a proven technique yet, it is important to have demonstrations of HT-ATES, to overcome uncertainties in technical, financial and regulatory fields as well as gain trust with developers to apply the technology. Key research questions relate to the integration and aquifer conditions.

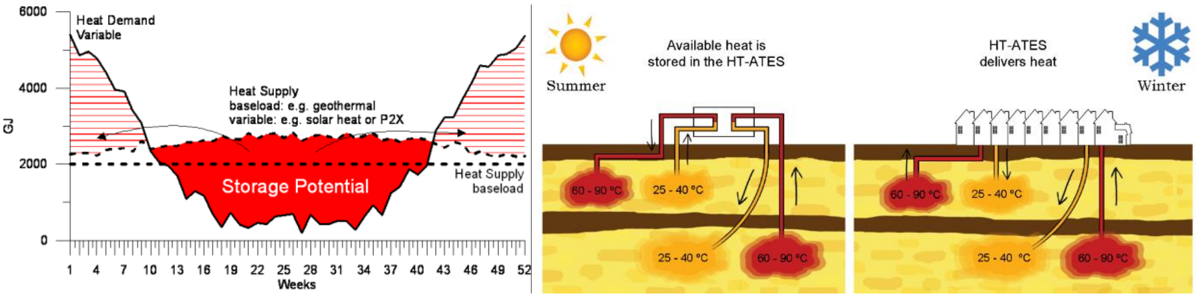

Figure 1. Left: benefit of HT-ATES heat storage (Hartog et al., 2017). Right: HT-ATES in combination with geothermal well working principle

In moderate climates like in the Netherlands, during winter months there is a large heat demand, while in the summer months there is a net heat surplus, e.g. from wind, solar, cooling, geothermal energy or residual heat from industries. To not let the excess heat go to waste, this heat can be stored and used in the winter months where there is demand for this heat. Aquifers provide space to store large amounts of heat in systems called aquifer thermal energy storage (ATES) systems. Low temperature ATES systems use a heat pump and are commonly applied in the Netherlands, with over 3 000 systems installed, and are typically installed in buildings with a cooling demand in the summer and a heating demand in the winter.

The general principle of ATES systems is that excess energy is stored as thermal energy in the groundwater, i.e. by increasing the temperature of the groundwater. The excess energy is mostly available in summer months where heat demand is low. When the heat demand is high, mostly in the winter months the heat extracted and used. Storage temperatures vary depending on project-specific heat supply and demand, but for commonly applied ATES systems are limited by permitting to a maximum of 25°C.

For geothermal systems (and several other sources of excess heat) a higher temperature is required to be stored, these systems are known as high-temperature (HT)-ATES systems (Drijver et al., 2019; Kallesøe and Vangkilde-Pedersen, 2019). Temperatures vary by project, but are limited by the temperature at which the water at a certain pressure conditions would be liquid. At the present time, provinces are granting pilot licences for projects, to test the wider applicability (SIKB, 2015).

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There are several potential advantages of HT-ATES systems but also potential disadvantages. Table 1 provides an overview of these pro and cons.

Table 1: Overview of advantages and disadvantages of HT-ATES systems.

Advantages	Disadvantages
Reduction of energy cost	Possible impact on groundwater quality
Positive climate effect (less emissions)	Feasible only for large (>200,000 m^3) capacity storage
Little space needed at the surface	Specific subsurface conditions required
Efficient use of heat sources	

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2. Heat availability and demand

2.1. Site description

The TRIAS Westland project consists of 2 geothermal doublets, which are commissioned in 2019 and 2021. The doublets have a combined maximum capacity of about 45 MW. A district heating network is used to distribute the heat from the wells to users: mainly greenhouses and several urban areas, Figure 2.

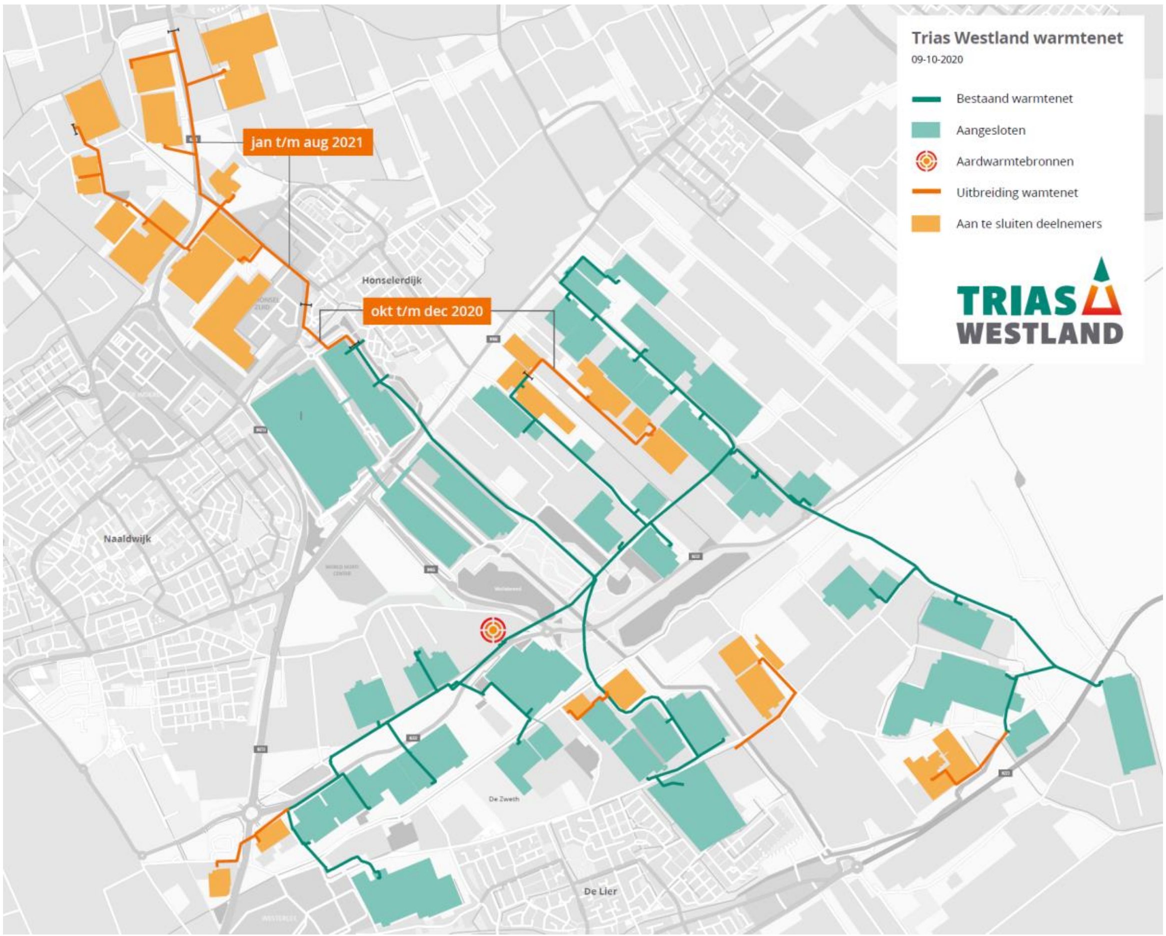

Figure 2. TRIAS Westland district heating network (www.triaswestland.nl)

2.2. Analysis of heat demand and supply

Supply data of both geothermal doublet and delivered heat are used to identify the required HT-ATES storage volumes for optimisation of heat utilisation from the geothermal doublets. Heat delivered data from 2022 shows that in the situation with 2 doublets and connected demand, that demand does not undercut 20 MW, also on the hottest days in summer. Since there is much more demand than there is delivered, the data from the summer periods is used to assess how much heat can

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be stored in the HT-ATES, assuming HVC will be able to sell any heat coming from the HT-ATES in winter.

Hence, the data is used to identify a bandwidth of the amount of heat that can be stored in the summer period. Maximal capacity of the geothermal wells is 45 MW, including the additional heat from the gas by catch. Also a scenario is explored in which the geothermal well reduces in capacity to 35 MW (including gas) during summer months (July and August). In the 2020 data, supply regularly drops to 0 MW, given the data of the summer 2022, the minimum of heat to be delivered to the users is set to 20 MW. To also create a worst case scenario for the amount of heat available to charge the HT ATES in one of the cases this minimum is set to 30 MW. Results are presented in Figure 3 and Table 2.

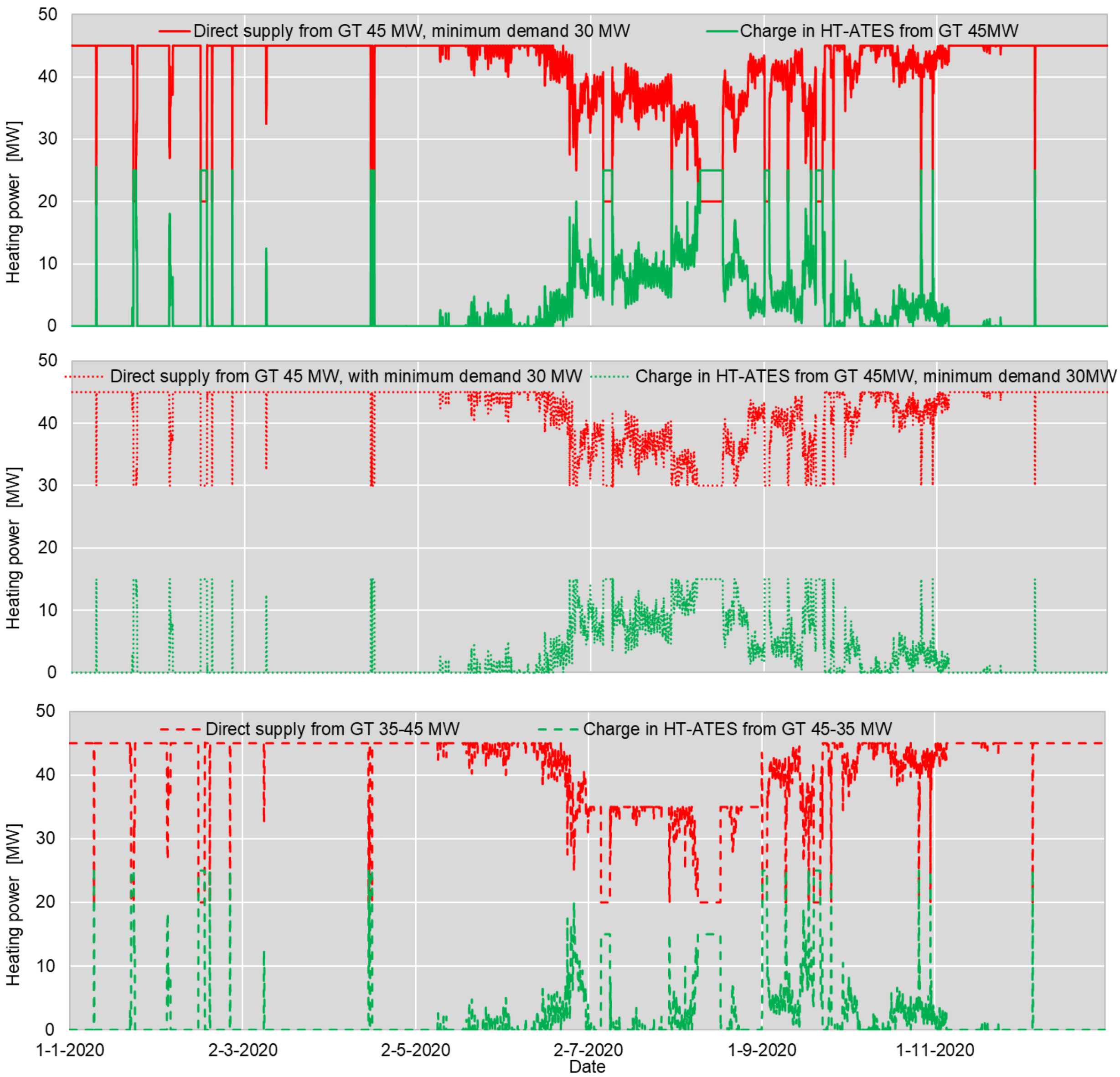

Figure 3. Heat directly delivered from the geothermal wells, together with the resulting heat that can be harvested to store in the HT-ATES, for different operational strategies and minimum demand during summer months.

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Table 2. Required HT-ATES capacity and size

Scenario	*GT* [MW]	*Total heat utilised** [TJ] *[%]****	*Utilised from HT-ATES*** [TJ]	*HT-ATES Volume* [Mm³]	*HT-ATES capacity* [MW – m³/hr]
0.No HT-ATES	45	1 315 *92%*	-	-	-
1.HT-ATES	45	1 390 *98%*	75	0.52	25 - 410
2.HT-ATES with min 30 MW delivery	45	1 375 96%	60	0.43	15 - 244
3. HT-ATES with GT 35 MW in summer	45-35	1 355 *98%*	40	0.31	25 - 410

*please note that at 45MW 24/7 the total yield from the geothermal wells is 1420 TJ/year. When GT production is reduced to 35MW in July and August, total yield is 1370 TJ/year.
**taking into account an initial estimation of the losses in HT-ATES: 30% for case 1 and 35% for case 2, and 40% for case 3.
***total percentage of heat coming from GT utilised

2.3. Conclusions heat demand and supply

Adding an HT-ATES to the TRIAS Westland district heating system offers the opportunity to additionally deliver about 75-40 TJ heat, depending on the demand conditions in summer. This results in an increase of 6%-points of the utilisation of the heat available from the geothermal wells, from 92% yield in the situation without HT-ATES to 96-98%.

The amount of heat the HT-ATES can deliver is relatively small compared to the total heat supply of both geothermal wells. Nonetheless, the amounts of heat in the 3 scenarios is sufficient to have an effective HT-ATES system. In addition to the extra sales of low carbon heat, the HT-ATES also offers back-up capacity in situations of down-time of the geothermal well, especially in scenarios 1 and 3 where HT-ATES capacity is sufficient to supply summer demand. In the following, scenarios 1 and 2 will be further evaluated[1].

[1] Case 3 was a hypothetical case, to see if in such situation still enough heat would be available to charge an HT-ATES, but when you have a HT-ATES, it is not logical to reduce geothermal production in summer.

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Box. Processing of monitoring data

The potential delivery of the connected greenhouses in 2020 is extrapolated to the total connected greenhouses (compared to data in
Figure 4, 2 times more before summer and 1.75 times more after summer, as the data includes the addition of greenhouses to the grid during summer new greenhouses, reflected in the (slightly) increased use after summer). This gives a bit higher values than the 2022 data shows that is delivered. The expected demand of the 2 residential areas connected to the system is provided by HVC. The total expected demand by the end of 2021 is presented in Figure 5, together with the capacity of the wells. It looks like that the geothermal wells can deliver virtually all required demand, However, we use delivered heat data as a basis, the demand in winter months is much higher. This data is used to identify how much It also shows that during a substantial period of the year heat from the geothermal well is not utilised, about 20% of the potential heat to be produced from the geothermal wells is not used.

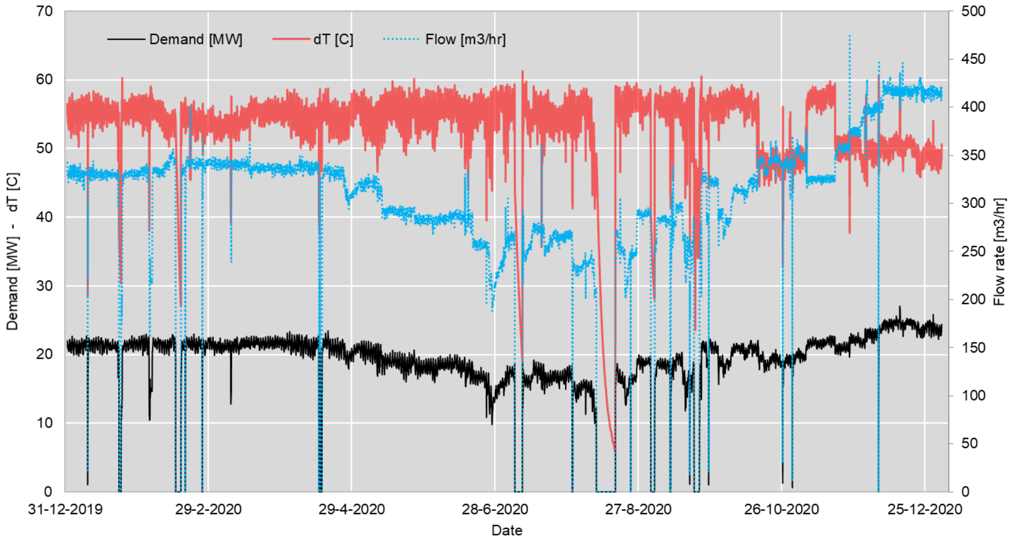

Figure 4. Supply data of the 1st geothermal doublet of Trias Westland

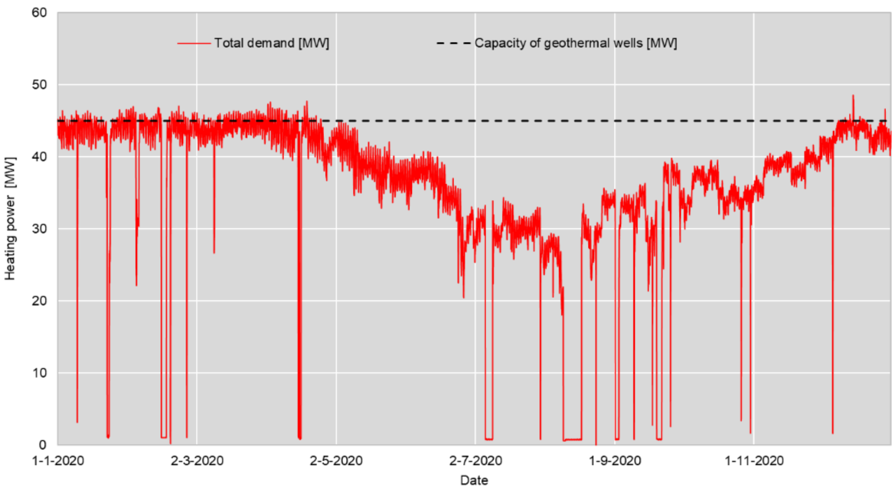

Figure 5. Total hourly demand by the end of 2021 compared to the capacity of the geothermal wells

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3. Geohydrology

In this chapter, the subsurface conditions at the TRIAS Westland location are analysed for the potential to install the HT-ATES wells with the requirements described in Table 2.

3.1. Criteria for suitable aquifers

The geohydrological conditions play an important role in the performance of an HT-ATES system. The thermal recovery efficiency and extraction temperature are the main indicators of the performance of an HT-ATES system. The efficiency is defined by the total extracted energy over the total injected energy during one recovery cycle. The amount of energy that can be extracted after storage is influenced by the losses that occur during storage.
The main geohydrological properties that affect heat loss in an HT-ATES system are: the vertical/horizontal hydraulic conductivity and thickness of the aquifer and the presence and thickness of confining layers. These properties all affect the losses due to conduction and buoyancy flow, triggered by the large differences in temperature, as schematically shown in Figure 6. The thickness of the aquifer, affects the geometric shape of the heat bubble, and with that the losses by conductions and dispersion. In addition to heat losses, legal and financial considerations affect the suitability of a layer.

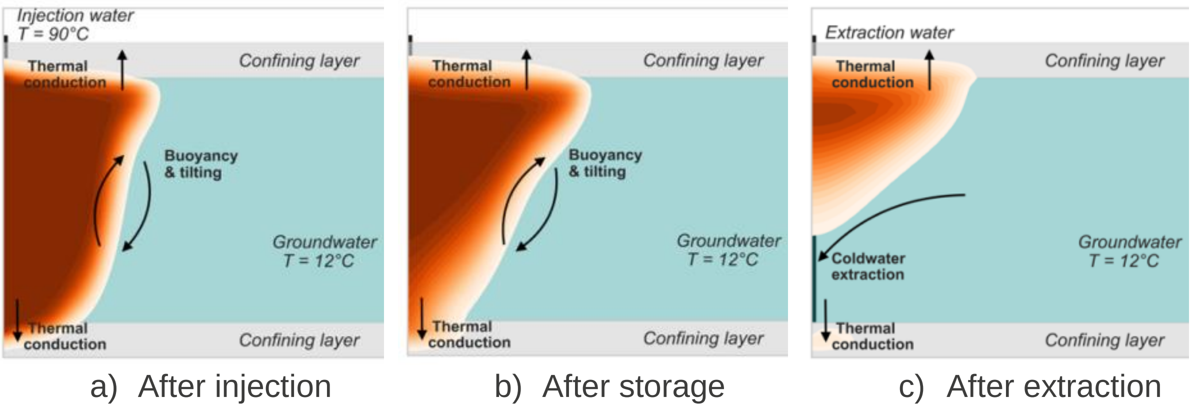

Figure 6. Buoyancy flow affecting extraction temperature of an HT-ATES system (Lopik et al., 2016).

3.1.1. Thickness

The thickness of the aquifer strongly affects the flow capacity of a well but also has effect on the heat losses of the system. Thermal losses occur at the boundaries of the hot water volume in the form of conduction and dispersion. A thin aquifer, results in a 'pancake' shaped heat plume in the aquifer, resulting in large conduction losses to the confining layers. On the other hand, thick layers result in 'candy cane' shaped heat plumes, causing conduction and dispersion losses to the aquifer and more buoyancy losses. These losses are minimised by applying a screen length that results in the smallest surface area (A) of the heat bubble for a given storage volume (V). Figure 7 shows the well optimal screen length/aquifer thickness (L) for different

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storage volumes, to minimise conduction and dispersion losses (minimise A/V). It shows that for a storage volume of 600 000 m^3 (approximately what is needed for the HT-ATES of TRIAS Westland, see Table 2) there is a 'flat' optimum at about 100 m, i.e. it is relatively insensitive to losses of heat via conduction and dispersion. Due to buoyancy losses it is better to have a smaller aquifer thickness, therefore a limiting value of about 45 m is preferred to also prevent large conduction and dispersion losses.

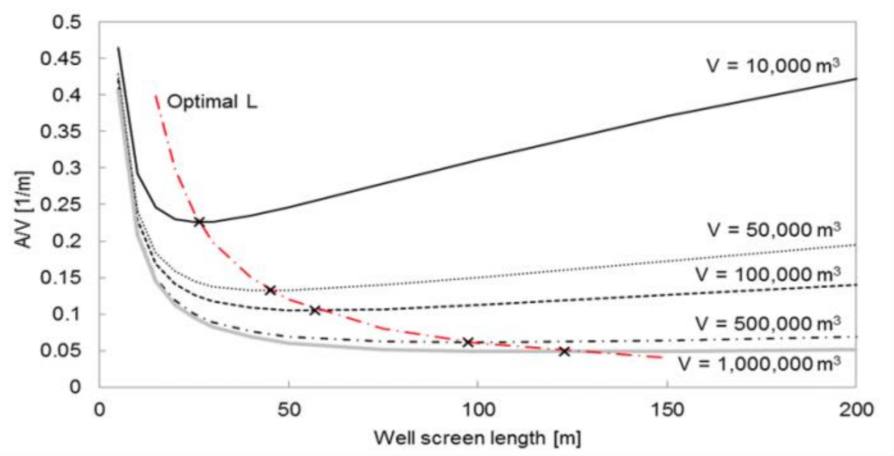

Figure 7. Optimum well screen length for given injection volumes, to minimise conduction losses (Bloemendal and Hartog, 2018).

3.1.2. Hydraulic conductivity

The hydraulic conductivity determines how easily water can flow in an aquifer. It depends on the intrinsic permeability, porosity and density and viscosity of the water, of which the latter two depend on temperature. A distinction is made between the vertical and horizontal hydraulic conductivity. To limit buoyancy losses, a small vertical hydraulic conductivity is preferred. The horizontal hydraulic conductivity determines the flow capacity of a well. Hence, a high horizontal conductivity is preferred to limit the number of wells, and with that also the drilling costs. Usually, the vertical hydraulic conductivity is lower than the horizontal, the ratio between the two is called the anisotropy factor. Usually it is the case that the deeper the aquifer, the larger the anisotropy and the smaller the absolute values are for the hydraulic conductivity.
Heterogeneity in the form of small clay layers in the aquifer, negatively affects the average horizontal aquifer hydraulic conductivity. However, small clay layers also result in lower vertical hydraulic conductivity which limits buoyancy flow, which in turn may result in a better overall performance of an HT-ATES system. It is also more complex to properly install the well screens at the required depth in heterogeneous conditions.

3.1.3. Geochemistry / microbiology

Temperature changes and/or mixing of groundwater may trigger biological activity, chemical reactions and/or mobilisation of components. HT-ATES induced changes in the chemical composition of the groundwater and/or microbiological activity may result in clogging of wells or groundwater quality deterioration. A known mineral precipitate is calcium carbonate which can clog the wells or the aquifer pores. The

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extent to which such processes occur depends strongly on the local geohydrological and geochemical conditions and the storage temperature.

3.1.4. Depth

When drilling deeper than 500m in the Netherlands, the Mining Law drilling guidelines are effective, requiring significant safety measures, strongly increasing the drilling costs (Wiebes, 2020)). Therefore, the aquifer depth is preferably shallower than 500m. The groundwater temperature increases with depth, by approximately 30°C each 1000m in the Netherlands. With an ambient temperature of 10°C at very shallow depths (~10 m below surface), at 500m depth the ambient groundwater will have a temperature of around 25°C. This will decrease the losses due to conduction and buoyancy flow. Table 3 provides an overview of pros and cons for application in shallow and deep

Table 3. Overview of pros and cons for application of HT-ATES in shallow and deep aquifers.

	Shallow	Deep
Pro	+cheap drilling +well known layers +high capacity	+Higher ambient groundwater temperature, fewer losses +Less impact to other groundwater users +Low hydraulic conductivity, limiting buoyancy flow +less change for microbiological effects
Con	-potential negative impact to other groundwater users -more heat losses -change for microbiological activity	-Low hydraulic conductivity, limiting capacity, increasing costs -Extra regulations concerning the Mining law. -Higher drilling costs -more uncertainties about characteristics

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3.2. Suitability of subsurface for HT-ATES at TRIAS Westland

In the Westland area, down to 500m depth, different formations are present that potentially could be suitable aquifers for HT-ATES. Based on the regional REGIS II model, aquifers are present in the Peize/Waalre formation, the Maassluis formation, the Oosterhout formation (Figure 8). Because the Province of Zuid-Holland reserved the Peize/Waalre formation solely for fresh water storage and recovery (ASR), this aquifer is not available for HT-ATES use.

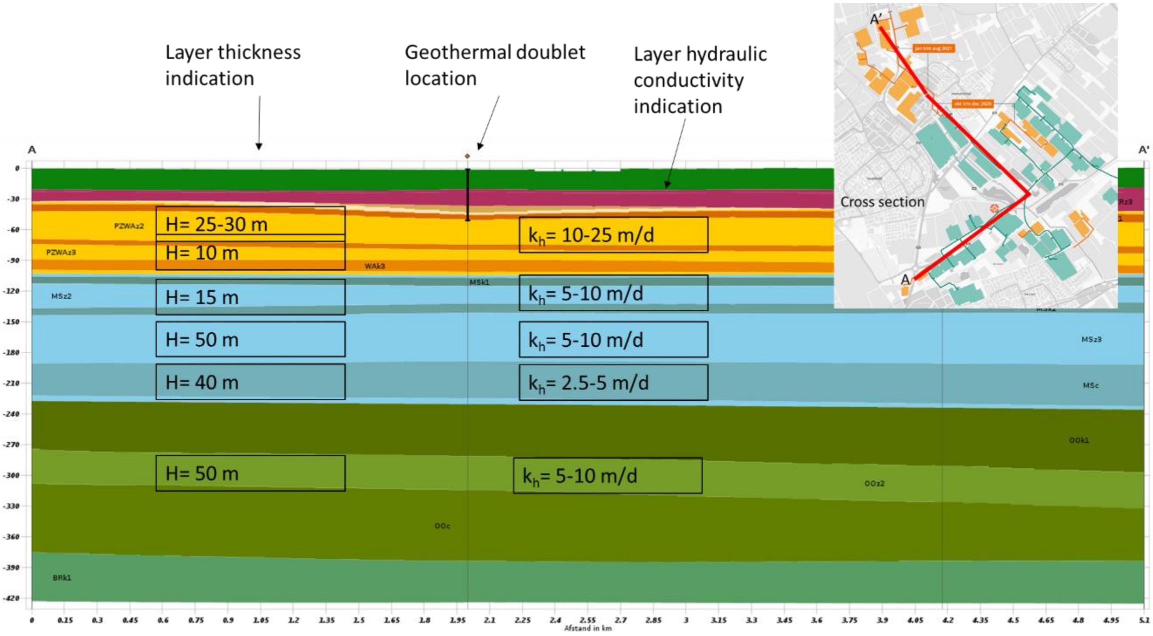

Figure 8. Geohydrological layering up to 400m depth according to the regional REGIS II model. Layers: formation Peize/Waalre (PZWA), formation Maassluis (MS) and the formation Oosterhout (OO). Figure and information is obtained from REGIS II (TNO, 2017).

The Brussels formation, which starts at 370m depth according to REGIS II, also has a sand member which has been identified as a potential aquifer for shallow geothermal (de Haan et al., 2020).

Hence, 3 potential formations are identified that have potential for HT-ATES in the TRIAS Westland area, the Maassluis formation, the Oosterhout formation and the Brussels formation.

3.2.1. Maassluis formation

The Maassluis formation is deposited in the late Pliocene and early Pleistocene (2.5-1.8 Ma). The depositional environment was a shallow marine near-coastal setting. Due to various stages of deposition and sea-level changes, the formation consist of irregular and discontinuous sand and clay layers. In general, a coarsening upward sequence is found in the deeper part of the formation and a fining upward sequence is found in the shallow part of the formation (Westerhoff, 2009).

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The local properties of the Maassluis formation were investigated with a deepening drilling in Maasdijk, which was combined with geothermal drilling work (Appendix II & III). Two potential aquifers are present in the Maassluis formation (Figure 10). Two clay layers are observed at 180 to 210m depth and 260m depth, according to SONO/LONO, Gamma Ray and the cuttings observations. The shallow zone, where measurements were done through the casing, shows less clear results. Nonetheless, the Gamma Ray measurements in combination with the cuttings observations show that another clay layer is present at 105 to 118m depth.

Regionally, this layering correlates to two other drillings in the surroundings of the Westland area (Figure 11, Figure 12). The depth and thickness of clay layers in the Maassluis formation is similar. The deeper sand aquifer is observed in all three drilling locations, although the aquifer is thinner in the South-East (GAAG05) and frequently intermitted with clay layers in the North-East (MNZ1). Although less distinct according to the Gamma Ray signal, the shallow aquifer also is present in the GAAG05 and MNZ1 wells. Hence, both aquifers are present in the wider region in the Westland.

The suitability of these aquifers is determined by their permeability and anisotropy. The horizontal hydraulic conductivity of these aquifers is estimated to be in the range between 2.5 to 10 m/d according to the REGIS II model and experience from other ATES systems in this formation.

The regional groundwater flow direction is West, towards the sea. But due to a large groundwater extraction in Delft, East from the village of Naaldwijk the groundwater flow direction is East. However, this extraction is being stopped over the course of a period of about 10 years. As a result, over time the groundwater flow direction in the Westland will be West everywhere. In both situations the head gradients in the Westland area are limited resulting in small groundwater flow velocities, usually <1 m/y.

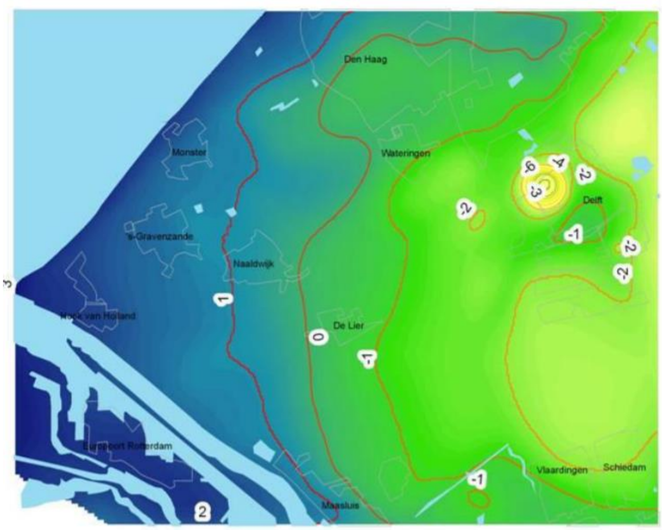

Figure 9. Groundwater heads in the combined 2nd/3rd aquifer. (Sanchez et al., 2012)

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3.2.2. Oosterhout formation

The Oosterhout formation is a marine sedimentary deposit from the late Miocene and Pliocene (5-2.5 Ma). Close towards the (former) coastline (South-East), the Oosterhout formation contains thick sand layers. Going further seaward (North-West), a higher fraction of clay was deposited (TNO-GDN, 2022a). For the subsurface in the Westland, mostly clay is observed to be present in the Oosterhout formation. According to the Gamma Ray signal and drilling report of the GAAG05 and MNZ01 drillings, also some sand(stone) is present, most likely at around -300m depth (Figure 8). Similar to the depth of the sand layer in the Oosterhout formation according to REGIS II. However, recent drillings in Rotterdam and Delft showed that the thickness of this sand layer is relatively small (2m and 1.5m respectively) (Vardon et al., 2022). Although the available data does not give a definitive answer, the suitability of the Oosterhout formation for HT-ATES is likely to be limited in this region. The hydraulic conductivity of these sands is estimated at 2.5 to 10 m/d (REGIS II).

3.2.3. Brussels sand member

The Brussels sand member is part of the Dongen formation, which is part of the lower north sea group ((TNO-GDN, 2022b). The Brussels sand member is not identified by TNO in the REGIS II model. A recent report shows that the Brussels sand is potentially present at a depth of 430 - 500m in the Westland region (de Haan et al., 2020). The Westland area is at a sharp transition area where the sediment at this depth are changing from chalk (in North-East) to Dongen formation deposits. The Gamma Ray signal of the GAAG05 and MsZ1 drillings indicate presence of sand(stone) between 450 and 500m, which also corresponds to the indication of sandstone layers in the drilling report. The horizontal hydraulic conductivity in the Brussels sand member was estimated at 0.86 m/d at a geothermal production site in the Netherlands, and for the Westland region, the horizontal hydraulic conductivity is estimated at 0.1 – 0.3 m/d (Geel et al., 2022).

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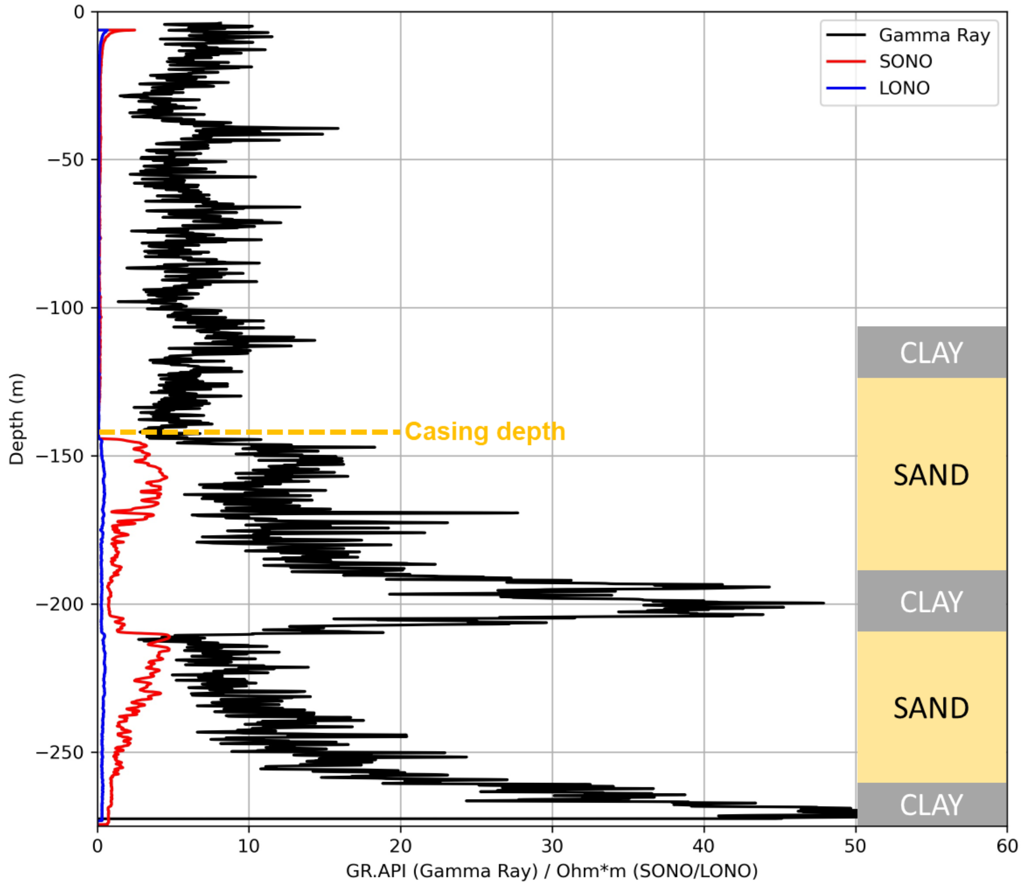

Figure 10 interpretation of the logging data obtained in the deepening drilling in Maasdijk (additional data in appendix IV) from surface level to 274m depth.

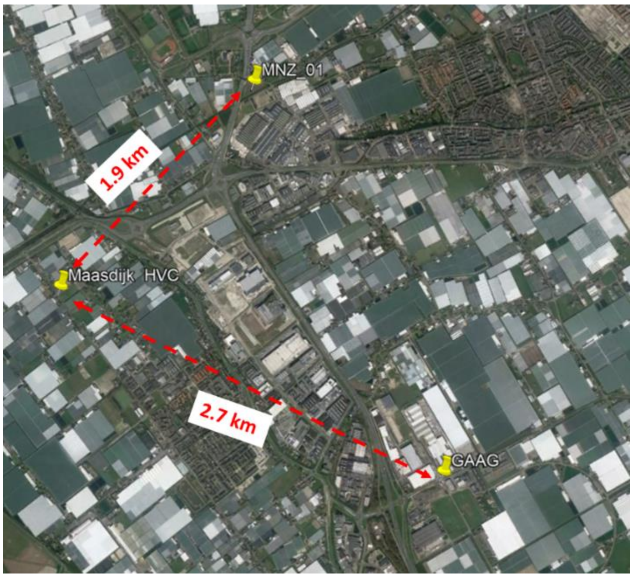

Figure 11 Location of two deep drillings (GAAG = 2.7km and MNZ_01 = 1.9km distance) compared to the Maasdijk drilling site.

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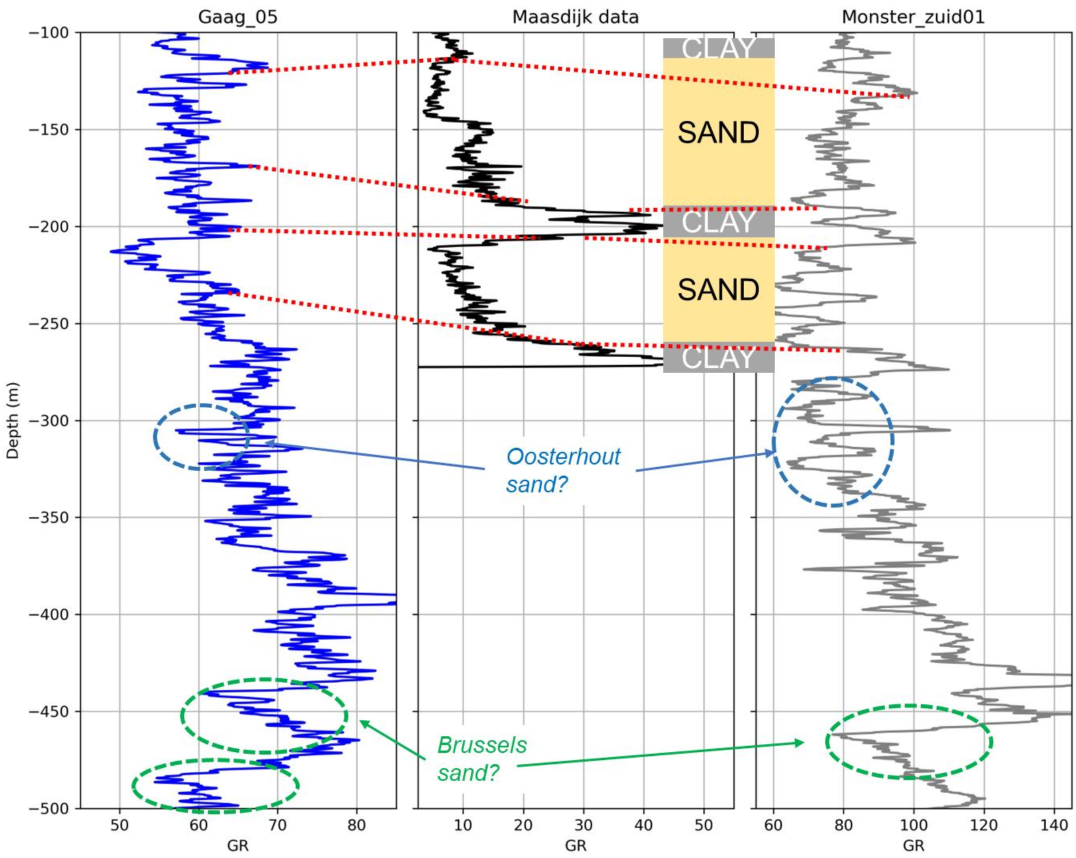

Figure 12 Regional correlation of the Gaag 05, Maasdijk and Monster zuid 01 drillings from 100 (start of Maassluis) to 500m depth. X,Y locations are given in Figure 11. Red dotted lines indicate the correlation between sand and clay layers in the Maassluis formation. Potential observations of sand layers in the Oosterhout and Brussels formation are indicated with blue and green circles respectively. The interpretation of the Gaag 05 and Monster zuid 01 are supported with information from the respective drillings reports (NLOG).

3.2.4. Conclusions aquifer suitability

Four potential aquifers are present in the subsurface of the Westland. The presence and suitability of the Oosterhout and Brussels formation (<500m depth) is highly uncertain. Moreover, drilling and installation costs are expected to be high in these formations.
In the Maassluis formation, two suitable aquifers are present. Uncertainty about the presence of these aquifers in Maassluis is low because various drillings (deepening Maasdijk, REGIS II, GAAG05, MNZ01) indicate the presence of these layers. One point of attention for the Maassluis aquifers is their relative shallow depth, application of HT-ATES in shallow layers have a larger risk of affecting other groundwater users/functions which are more often present in shallow confining layers, compared to deep ones.

Table 4 summarizes the positive and negative properties of the 4 aquifers under consideration. From Table 4 it is concluded that the two aquifers in the Maassluis formation are suitable for HT-ATES and their suitability is therefore investigated

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further in the next section, by assessing the recovery efficiency of the HT-ATES storage volumes identified in Chapter 2.

Table 4. Summary of the potential storage aquifers for HT-ATES and their Pro's and Con's for application in the Maassluis and Oosterhout formation.

	Maassluis shallow aquifer	**Maassluis deep aquifer**	**Oosterhout**	**Brussels sand**
Depth (m -sl)	116	210	~300	~450 – 500
Thickness (m)	54	30	?	< 20
Pro	- Thickness, large capacity - Less deep, lower drilling costs	- well insulated with confining layers - Thickness, less buoyancy flow	- Less impact expected to other subsurface functions - well insulated with confining layers	- Minor impact on other subsurface functions - No buoyancy flow expected
Con	- potential higher heat losses due to buoyancy - uncertainties about confining top layer - higher risks of temperature effects to shallow aquifers	- higher drilling costs compared to shallow aquifer	- thin layer - high drilling costs, deep and more wells needed - more uncertainties	- high drilling costs - low capacity
Data uncertainty	LOW	LOW	HIGH	HIGH

3.3. Simulation of HT-ATES performance

In this section, the potential performance of the two aquifers in the Maassluis formation is investigated using the thermo-hydraulic simulator SEAWAT. As the sand thickness varies between layers, and the hydraulic conductivity is not known exactly, a pre-defined set of simulations is set-up to investigate the sensitivity of this uncertainty.

3.3.1. Setup

Model setup

The SEAWATv4 model, which combines the MODFLOW and MT3DMS models, is used to simulate density and viscosity dependent flow of heat and groundwater. These simulations are of exploratory nature, hence the following straightforward model set-up is applied:

- Both the hot and warm well are simulated separately using an axisymmetric grid, interaction between the wells or ambient groundwater flow are not taken into account.
- Fully penetrating wells are implemented.

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- Hydraulic conductivity is anisotropic and varied according to the scenarios in the following section.
- The aquifers and aquitards are modelled as homogeneous layers with isotropic thermal properties. Hence, well in- and out-flow are distributed evenly along the aquifer thickness.
- The injection and extraction volume is distributed over the year by a sine function.
- The model input and output, recorded and processed per day.

Table 5 schematic representation of the subsurface as applied in the model for the base case scenario (deep aquifer).

Top (m -sl)	Bottom (m -sl)	Type	K_h (m/d)	Kv (m/d)	Porosity (-)	Sediment thermal conductivity (W/m/°K)
0	-20	aquitard	0.001	0.0005	0.4	2
-20	-50	aquifer	5	2.5	0.3	2
-50	-70	aquitard	0.001	0.0005	0.4	2

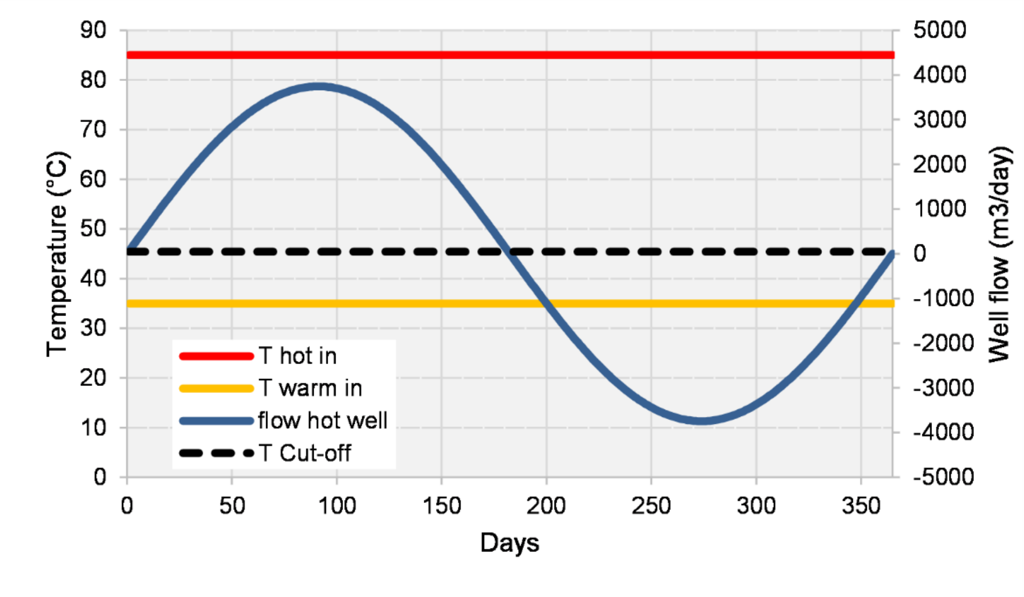

Figure 13 Applied flows and injection temperatures for scenario 2 (435,000 $m^3/_{year}$)

Scenarios

In all scenarios the storage temperature of the hot well is 85 °C, the warm wells storage temperature is 35°C. For worst-case efficiency calculation, a cut-off temperature of 45°C is assumed for all scenarios (Table 6).

For the system design of HT-ATES combined with min 30 MW delivery of the geothermal well, the calculated storage volume is 430,000 m^3/year (Table 2). This is the storage volume used for most simulations in this part (Table 6, scen. 2). To evaluate the effect of different storage volumes, the estimated maximum (scen. 3)

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and minimum (scen. 1) size of the HT-ATES are also simulated, following the scenarios identified in Table 2.

The deep Maassluis aquifer is expected to be the most suitable aquifer for this system (Table 7). Three additional cases are defined to assess the effect of:

1) The shallow aquifer instead of the deeper aquifer
2) A lower vertical hydraulic conductivity
3) a higher horizontal and vertical hydraulic conductivity

In total, 6 simulations are performed for a period of 10 years. This is long enough to have a good idea of the long-term performance of each scenario.

Table 6. HT-ATES system design scenarios evaluated

	Storage temperature [°C]	Storage temperature warm [°C]	Cut off temperature [°C]	Storage volume [m³]
Scenario 1	85	35	45	525,000
Scenario 2	85	35	45	435,000
Scenario 3	85	35	45	310,000

Table 7. Cases for subsurface characteristics for simulations. These 4 cases have been simulated using scenario 2 for the storage volume (435,000 m³).

	Aquifer thickness [m]	K_h [m/d]	Anisotropy [-]	K_v [m/d]
Base case	30	5	2	2.5
Case 1: shallow layer	54	5	2	2.5
Case 2: lower K_v	30	5	5	1
Case 3: higher K	30	10	2	5

Assessment framework

The performance of the wells and the system is analysed by calculating the recovery efficiency:

$$\eta_{th} = \frac{E_{out}}{E_{in}} = \sum \frac{\Delta T_{out} \cdot V \cdot c_w}{\Delta T_{in} \cdot V \cdot c_w}$$

Where E_{out} is the total recovered energy and E_{in} the total stored amount of energy. ΔT is the respective temperature difference (see below), V the groundwater flow (m³) and c_w the volumetric heat capacity of water (~4.18 MJ/m³).

The recovery efficiency of the individual wells is calculated relative to the ambient groundwater temperature (T_{amb}), which is set at 12 °C in this simulation. So, the ΔT of the hot or warm well is calculated as $T_{in/out}$-T_{amb}.

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Based on the performance of the two wells, the performance of the system as a whole is calculated using the temperature difference between the hot well and the warm well: $\Delta T_{sys}=T_{hot}-T_{warm}$.

3.3.2. Results

During storage, heat is conducted into the aquitards above and below the aquifer and into the aquifer surroundings (Figure 14). After 10 years, the 50°C contour travelled almost 10 meters in the aquitard at the top. Also, the thermal front tilts as a result of the density difference between the stored hot (light) and ambient cold (dense) groundwater. This results in the extraction of relatively cold groundwater at the end of the unloading cycle (right, Figure 14).

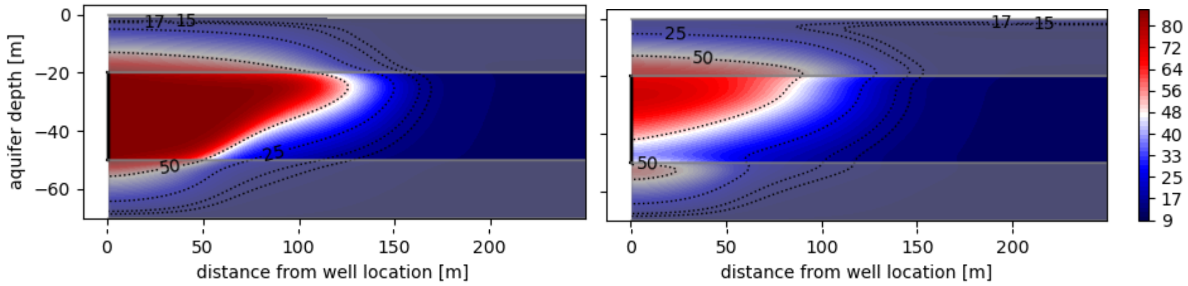

Figure 14 Cross-section of the simulated temperature in the hot well after 10 years of operation. Left: when the well is fully loaded (end of summer) and right: at end of unloading cycle (end of winter).

The temperature in the well is given in Figure 15. During injection, the temperature in the well is equal to the injection temperature. During extraction, the temperature decreases because increasingly more colder groundwater is extracted because of the energy losses that occur during storage. During heat delivery, water is extracted from the hot well until the cut-off temperature is reached (45°C). This only occurs at the end of the first storage cycle (day 342/365). As the lost energy heats up the subsurface, the well temperature decreases less and less with each year of operation. This is the case for both the hot and the warm well.

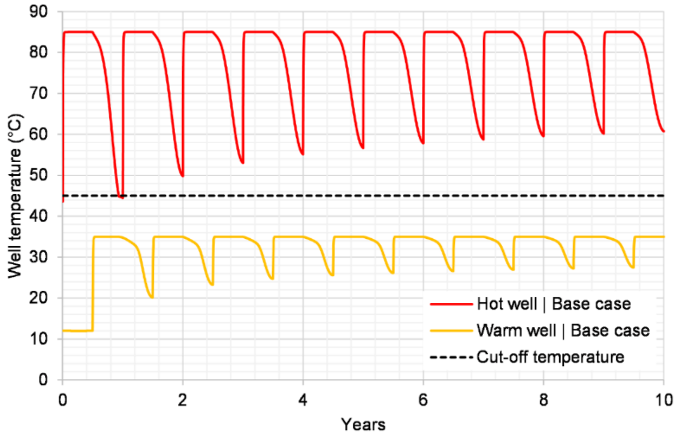

Figure 15 Well temperatures of the Base case (scenario 2). The Cut-off is reached once, at the end of unloading season in year 1.

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The yearly recovered energy is calculated for the individual wells and the system (Figure 16). For the warm well, the recovery efficiency is not calculated for the first year because no heat that was previously stored was recovered (starts with extraction of ambient groundwater). The warm well has a higher recovery efficiency compared to the hot well, this occurs because the energy losses due to buoyancy flow are stronger for the hot well. After 3 years of operation, both wells have already a recovery efficiency >80%, and for the warm well, this increases to 90% after 10 years of operation. For the hot well, the recovery efficiency increases only very modestly after the first 3 years of operation, resulting in 85% recovery efficiency in year 10 of operation. The system recovery efficiency takes account for the energy losses in the warm and hot well. Therefore, the recovery efficiency is lower for the system as a whole. Because the system operates at a ΔT of 50°C between the hot and warm well, the resulting system performance is high, with 70% after 4 years and already 78% after 10 years.

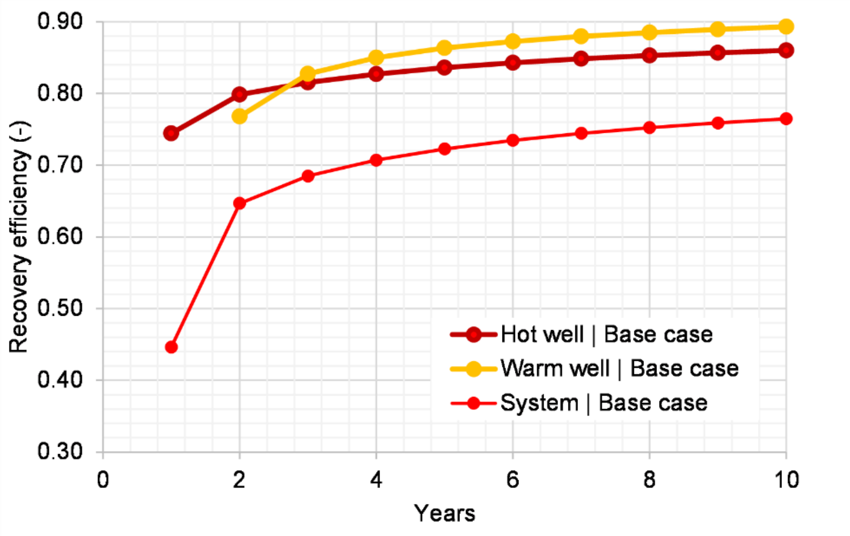

Figure 16 The recovery efficiency of the individual hot and warm well and the system for 10 years of the Base case (scenario 2). The system efficiency is the result of the energy losses in the hot and warm well.

To assess the effect of different system designs (storage volumes) or variation in subsurface conditions, the base case (scenario 2) is compared to additional simulations (Figure 17). An increase of 90,000 m^3/year in storage volume (scenario 1) results in a slightly better performance of 1%, while a smaller storage volume (decrease of 125,000 m^3/year) results in a decrease of the system recovery efficiency of 3% (Figure 17A).
The varied subsurface conditions have a stronger effect on the system recovery efficiency (Figure 17B). When the aquifer is used, with a thickness of 54m (case 1), the performance of the system decreases from 76 to 66% in year 10 of operation. When the aquifer thickness increases, also the potential for buoyancy flow increases which results in an increase of the energy losses (mainly in the hot well). The same effect is observed when the hydraulic conductivity would turn-out higher then currently expected 10 m/d (case 3). Again, stronger buoyancy flow leads to a decrease in performance (70% compared to 76% system recovery in year 10). The effect of the anisotropy variation (case 2) is opposite and minor (1% increase). This occurs because the vertical hydraulic conductivity decreases which results in

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reduced impact of buoyancy flow. The simulation results suggest that performance is more sensitive for higher vertical hydraulic conductivity, than when it is lower, compared to the base case.

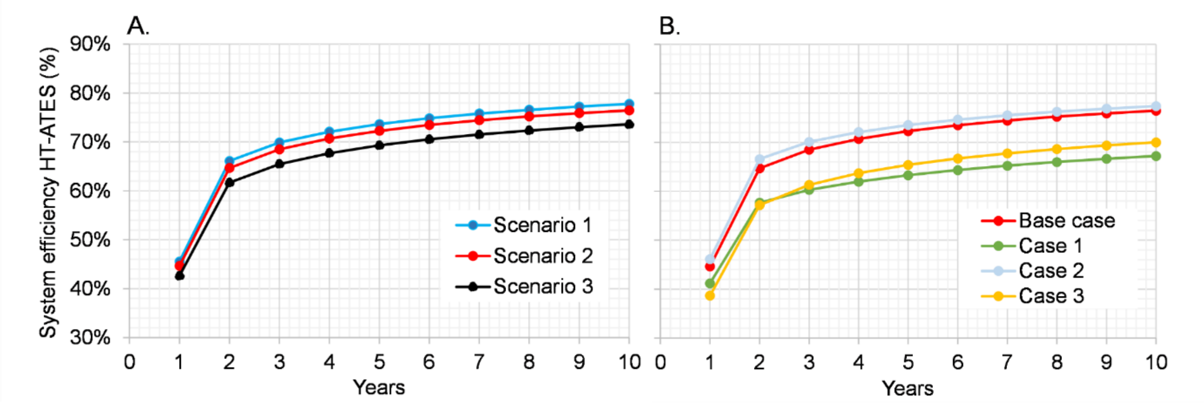

Figure 17 The system efficiency of the 6 scenarios that were varied in this study. A. for variation in the system design (storage volume) and B. for the varying subsurface conditions.

3.4. Conclusions geohydrology

In the subsurface of the Westland multiple aquifers with potential for HT-ATES are present. The two aquifers in the Maassluis formation are most suitable. A sensitivity analysis of HT-ATES performance for variation in both the system design (storage volume) and the subsurface conditions show that the deepest aquifer in the Maassluis formation between 210 and 240m depth has the highest potential for seasonal heat storage with system recovery efficiencies higher than 65% and 75% after 3 and10 years respectively. The performance is a bit sensitive to higher vertical hydraulic conductivity. To conclude, the geohydrology in this area is suitable for HT-ATES. The characteristics of the most suitable aquifer identified in this chapter, are used to determine the financial feasibility in the next chapter.

Furthermore, the calculated losses are generally lower, than the assumed losses in Table 2, hence the amount of heat to be expected delivered is a realistic minimum value and likely to be higher in practice.

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4. Financial feasibility

The specific costs of the HT-ATES system are divided in two categories, CAPEX (capital expenditures) occurring during system build/installation phase and OPEX (operational expenditures) recurring throughout the operation timeline of the installation. Both OPEX and CAPEX values are developed to be as representative as possible to real costs that would be incurred for HT-ATES installation with previously outlined technical requirements. This is a quick scan study, the costs and savings are interpolated from a recent cost estimate carried out for a nearby HT-ATES in Delft of similar size and in the same target aquifer (Bloemendal et al., 2020).

4.1. HT-ATES system cost

4.1.1. Investment costs (CAPEX)

The costs are based on the required well design for the scenarios 1 and 2, Table 2. Following the Dutch ATES well design standards this results in a maximum capacity of a single (1 m diameter) well for injection in the Maassluis formation of about 40 m^3/hr (NVOE, 2006). Given that flow rates can be higher in both warm and hot wells of HT-ATES, this results in the requirement of 10 and 6 warm wells and 5 and 3 hot wells for scenarios 1 and 2 respectively.

The capital expenditure of HT-ATES system installation are attributed to following elements:

- HT-ATES wells
- Surface plant
- Distribution network (connections & piping)
- Permits, engineering and construction

Table 8 shows the estimated costs (excluding VAT) of the complete HT-ATES system. The costs outlined are representative on industry standard estimations, based on experience in ATES and geothermal system development.

Table 8. CAPEX breakdown of expected HT-ATES installation for Maassluis

	Scenario 1	Scenario 2	
HT-ATES wells	2,695	1,617	*k€*
Surface plant	970	737	*k€*
Permits, Engineering & construction	300	300	*k€*
Contingency	300	200	*k€*
Total	**4,265**	**2,854**	*k€*

HT-ATES wells

The HT-ATES wells post consist of hot and warm wells, completions, filter, electric submersible pump (ESP), piping and cabling. Cost for realisation of the system, such

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as drilling, cleaning and installation of the various instruments, are included as well. The breakdown of well costs can be seen in Table 9. Cost estimates of the hot wells show the highest degree of uncertainty as high operating temperatures require non-standard ATES materials, like glass-fibre reinforced epoxy (GRE) piping and stainless steel filters. The major differences between the systems arise due to the differences in capacity.

Table 9. CAPEX breakdown of HT-ATES wells for Maassluis.

	Scenario 1	Scenario 2	Unit
Hot well	***259***		***k€***
Drilling	*129*		*k€*
ESP	*100*		*k€*
Appendages	*20*		*k€*
Man hole	*10*		*k€*
Warm well	***140***		***k€***
Drilling	*100*		*k€*
ESP	*15*		*k€*
Appendages	*15*		*k€*
Man hole	*10*		*k€*
# hot wells	**5**	**3**	
# warm wells	**10**	**6**	
Total	**2,695**	**1,617**	***k€***

Surface plant

The HT-ATES surface plant is a surface installation that will be integrated within the existing heat plant buildings and consist of the piping between the wells, heat exchangers, buffer system (20m^3), distribution pump and water treatment installation. Table 10 shows expected costs of HT-ATES system installation in Maassluis formation, based on industry standard and target formation specifics. The differences arise due to the different flow rate required.

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Table 10. CAPEX breakdown of Surface plant

	Scenario 1	Scenario 2	
Piping	460	345	*k€*
Heat exchangers	280	210	*k€*
Distribution pump	20	15	*k€*
Buffer system	30	25	*k€*
Water treatment installation	30	20	*k€*
Building construction	50	50	*k€*
Connection to the district heat network	100	75	*k€*
Total	**970**	**740**	***k€***

4.1.2. Operational costs (OPEX)

The HT-ATES system operational expenses are anticipated from (Table 11 and Table 12):

- Maintenance and replacement of parts
- Water treatment
- Monitoring and water quality assessment
- Electricity use (Table 12)

Maintenance

Regarding the yearly maintenance costs (Table 11), the largest costs come from the 5 yearly regeneration of the wells and replacement of the ESP. In long run maintenance other replacement cost are taken into account. Small maintenance represent various maintenance activities, mostly man-hours, that will be required to ensure optimal performance during years of operation.

Water treatment

It is assumed that hydrochloric acid solution dosing will be utilised in both target layers to treat stored water. It is estimated that 5 litres of HCl (30% concentration) will be required for 1 MWh of energy stored. Based on this assumption, and a cost of 200 €/tonne of HCl (including transportation), it is calculated that for water treatment an investment of 1.15 €/MWh (0.32 €/GJ) of stored heat is required. For expected amount of energy stored yearly, the average OPEX cost for water treatment comes to 24k€ and 19k€ per year for scenario 1 and 2 respectively.

Monitoring

OPEX costs for monitoring are composed of compensation for monitoring, interpretation and the yearly inspection. The required certification costs are also covered under this operational cost estimation.

Table 11. Yearly maintenance OPEX breakdown of HT-ATES system.

	Scenario 1	Scenario 2

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Maintenance of the wells	**250**	**175**	*k€*
- Long run maintenance	*30*	20	*k€*
- Small maintenance	*45*	30	*k€*
- Electrical submersible pump (ESP), hot	*75*	50	*k€*
- Regeneration	*100*	75	*k€*
Maintenance of the surface plant	**55**	**55**	*k€*
- Long-term maintenance	*25*	*25*	*k€*
- Small maintenance	*30*	*30*	*k€*
Water treatment	**24**	**19**	*k€*
Monitoring and reporting	**35**	**35**	*k€*
Total	**364**	**284**	***k€***

Electricity Consumption

The electricity costs for the facility operation (Table 12) is based on the energy needs of the pumps, with other electricity demanding machinery costs assumed to be sufficiently represented under the pump energy use estimations (explained below). To estimate electricity use in the system, expected pressure of the system (and hydraulic power needed), flowrate-based estimations of system loading/ discharging hours per year, as well as an inefficiency factor were taken into account. Also the electricity required for the geothermal wells to produce the heat that is stored is included here.

Table 12. Yearly electricity cost (OPEX) breakdown of HT-ATES system.

	Scenario 1	Scenario 2	
Electricity needed for HT-ATES pumps (charging + discharging)	5.3	4.3	*TJ*
Electricity needed for GT-pumps to charge HT-ATES	5.5	4.5	*TJ*
Total electricity use	**10.8**	**8.8**	*TJ/year*
Electricity cost (+ tax)	0.1	0.1	*€/kWh*
Total electricity costs	**300**	**244**	*k€/year*

Table 13 gives final values of yearly expenses expected for the HT-ATES operation and calculated heat storage cost per GJ delivered. The largest contribution to operational expenses of HT-ATES plant operation comes from electricity use of the facility operation, as well as man hours and supervision/maintenance of the facility. Without taking into account extra costs of research oriented expenses in operational sense, operational costs per year can be estimated quite accurately from industry ATES project development and operation experience, and industry standards.

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Table 13. Total cost per year for HT-ATES system, excluding savings

	Scenario 1	Scenario 2	
Total OPEX costs	**664**	**528**	*k€/year*
(based on total maintenance + electricity)			
Yearly depreciation	**853**	**571**	*k€/year*
(CAPEX is written of over 5 years)			
Total	**1,517**	**1,099**	*k€/year*

4.2. HT-ATES system savings

4.2.1. HT-ATES system CO_2 saving cost benefits

The financial benefit arise from both the reduction of both natural gas purchases as well as reduction in CO_2 emission rights purchases, both quantified in Table 14. Please note that:

- In this case it is not clear who saves the CO2 emission rights and can account for these costs (the system operator, or the users of heat (greenhouses))
- Any additional revenues related to the increased subsidy from the geothermal well (SDE+) are not taken into account.
- Pre-Ukrainian war price levels for electricity and gas are used
- CAPEX for gas fired boilers or CHP in the case of no HT-ATES are not taken into account.

4.3. Conclusion financial feasibility

The yearly costs (including depreciation) for the HT-ATES to deliver the 75 and 60 TJ of heat respectively (1,5 and 1 M€, resp.) are smaller than would be needed to supply that same amount of heat with a gas fired boiler (2,5 and 2 M€, resp.).

If the CO_2 emissions costs savings are excluded, the direct costs for gas purchase are still higher than installing and operating an HT-ATES would be. The relative savings are better for scenario 2 because that set-up would require a considerable lower flow rate, and with that also lower required investment for the HT-ATES wells.

The costs to provide the 75 and 60 TJ, result in a heat price of around 20 and 15 €/GJ, respectively.
The additional costs of requiring a HT heat pump would considerably affect the financial feasibility. However, given the low return temperature in the district heating network, it is not likely a HT heat pump is needed, which was therefore assumed in this study.

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Table 14. Benefits (financial + emission reduction) of HT-ATES system installation

	Scenario 1	Scenario 2	
Natural gas reduction	2,380,952	1,904,762	*m^3*
Emission reduction of CO_2	4,229	3,383	*ton CO_2*
Cost per tonne CO_2 emitted with tax (emission rights)	25	25	*€/ton CO_2*
Cost per m^3 of natural gas with tax	1	1	*€/m^3*
Total emission reduction savings	106	85	*k€/year*
Total natural gas purchase reduction savings	2,381	1,905	*k€/year*
Total savings due to HT-ATES installation	**2,487**	**1,989**	***k€**/year*

The costs used originate from pre-Ukranian war levels. The energy costs levels are likely to remain much higher then were applied in this study, and will certainly vary stronger. Which in itself can be a good argument to be as self sufficient as possible. When applying energy costs for both electricity and gas twice as high compared to pre-Ukranian war, the yearly profits double. So this is beneficial for the financial feasibility of HT-ATES.

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5. Policy and permit

5.1. Legal framework

The legal framework that needs to be abided by for HT-ATES depends on the depth at which HT-ATES will be installed. Until 500 m below ground level (bgl) the water law regime is applicable, while at depths of over 500 m bgl, the Mining law is applicable. Pressure, temperatures and the risk of uncontrolled outflow of hydrocarbons increase with depth. For this reason the activities at depths of > 500 m bgl are subject to a stringent safety regime. The overview in Figure 18 shows the characteristics of the different regimes.

Figure 18. Characteristics of Water Law versus Mining Law.

This study focuses on aquifers up to 500 m-mv depth, which is within the scope of the Water Law regime. The planned HT-ATES depth of this project does not reach a deeper than 500 meters with (planned) targeting of the Maassluis or Oosterhout formations. Hence, the Water Law is the relevant law.

5.1.1. Rules for HT-ATES under the Water law

Both ATES and HT-ATES are ‘open loop geothermal energy systems’: systems that store and extract cold or heat from aquifers by using the groundwater as a carrier for heat transport. Extraction and infiltration of groundwater for the benefit of ATES is subject to licenses under the Water Law. ‘Gedeputeerde Staten’ of the province is the competent authority (article 6.4 of the Water Law).

5.1.2. Amended Decree on ATES and BHE systems

The Wijzigingsbesluit Bodemenergiesystemen (Schultz van Haegen, 2013) came into force on July 1st, 2013. Article 6.11 of the Water Decree states that infiltration temperatures for ATES are not allowed to exceed 25 °C and may not have long-term heat surplus in the subsurface. However, exceptions can be made to the interest of effective usage of the ATES system. On this basis the HT-ATES system are eligible to be licensed. How the license consideration takes place is not described in the legal documents.

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5.1.3. Provincial policy for permitting HT-ATES

Provinces have set a common approach for permit issuing of ATES (SIKB, 2015) and BHE systems, “Besluitvorming Uitvoerings Methode” (BUM). HT-ATES does not meet the standard requirements set out in the BUM, due to the infiltration temperature exceeding 25 °C and the long-term heat surplus in the soil. The BUM states that it is possible to deviate from the standard regulations in case systems are implemented as a research project, and the BUM concretely states that HT-ATES is also seen as such. It can be concluded that provinces may grant licenses for HT-ATES pilot projects and that no other interests are harmed.

The province of South Holland has shaped its policy regarding ATES in the work program ‘Bodem en Ondergrond 2016-2020’ (Zuid-Holland, 2015). The province of South Holland states in this document that the province is willing to allow HT-ATES pilot projects. The province of South Holland has granted the license for the HT-ATES pilot project Koppert-Cress as part of the Green Deal. Besides this project, there are several initiatives being discussed where HT-ATES systems are connected to geothermal sources and district heat networks.

5.1.4. Required permits

Development of HT-ATES at TRIAS Westland will require a water license. For this purpose, the effects of the ATES system must be quantified by doing in an impact study. ‘Gedeputeerde Staten’ of the province of South Holland is the competent authority. Executive body “Omgevingsdienst Haaglanden: carries out the assessment of permit requests and issues permits for ATES systems on behalf Gedeputeerde Staten of the province of South Holland. The procedure time for applying for the Water law license is approximately 8 weeks. In the case of complex environmental interests, the province may deviate from this and declare the extensive procedure (lasting 6 months) is applicable. Since HT-ATES is not a standard/regular ATES system the 6 months procedure applies to this initiative. In practice, it is desirable to coordinate the licensing procedure with the competent authority before starting the official legal procedure for obtaining the Water law license.

5.2. Interference with other interests

5.2.1. Other subsurface users

Due to the many systems in the area it is important to have the overview of the locations of all existing ATES systems as well as geothermal wells. In the Westland area there are various ATES systems operational, with additional systems planned for the near future (Figure 19).

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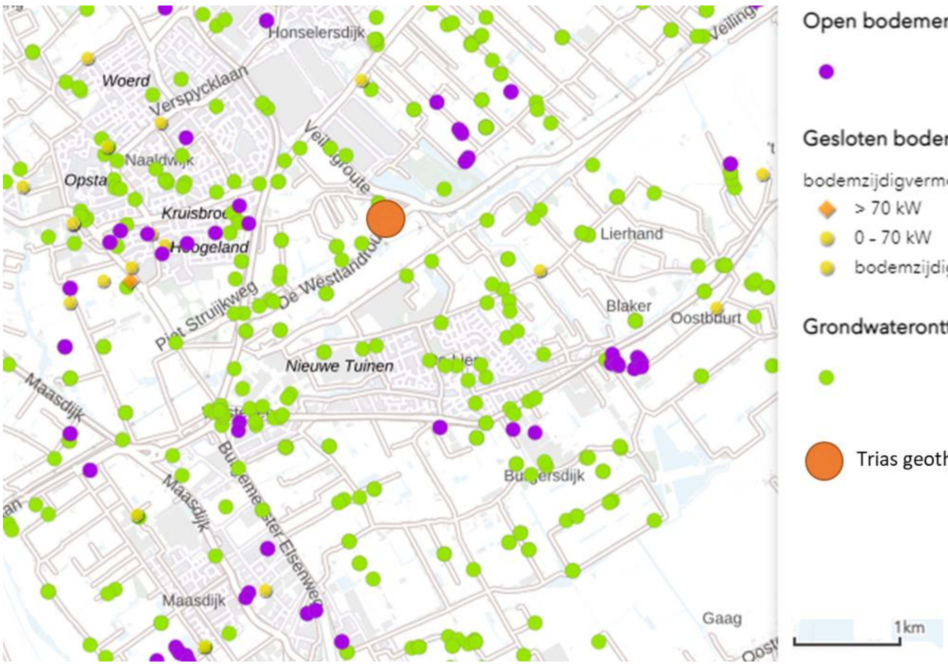

Figure 19. Existing ATES and BHE systems (www.WKOtool.nl)

The location of the HT-ATES needs to be selected such that minimal thermal disturbance of the existing ATES systems and groundwater extractions/storage and recovery systems. In the close vicinity of the geothermal plant location there are no ATES systems present, however there are some groundwater extractions. Groundwater extractions are typically located in the shallow aquifer in the Westland. Hence, heating of this aquifer due to heat losses from the HT-ATES should be assessed when identifying the exact location of the HT-ATES. Depending on the integration of the HT-ATES integration in the DHN, exact location and assessment of impact on other users is to be elaborated on in the next phase.

5.2.2. Stakeholder management

A crucial element in the successful development of both the geothermal well and HT-ATES projects is stakeholders management. Such projects require cooperation with the relevant stakeholders like the province, municipality, water authority, interest groups, landowners, people living in the vicinity, etc. As the geothermal well project team is several years ahead of the HT-ATES project, and both projects aim for using the same locale, close cooperation and eventually integrating stakeholder management and communication activities of the HT-ATES system will be beneficial. In depth stakeholder analysis and developing a stakeholders management strategy will be an important subject in the next phase.

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5.3. Policy & permit risks assessment

Item	Risk	Mitigation
Permit not issued	High	Involve province, municipality and other stakeholders in early stage, agree on process and criteria for issuing of permits.
Public resistance, causing delays in the permit process or even prevent issuing of permit	High	Close cooperation with project team of the geothermal well. Streamline and integrate stakeholder management and communication activities of the HT-ATES with the stakeholder management and communication of the geothermal well.
HT-ATES impact cold wells of existing ATES systems or other interests. Permit is withdrawn during operation.	Medium	Careful impact assessment during design. Keep sufficient distance between the hot HT-ATES and cold ATES wells and other interests. Possibly the well configuration needs to be adjusted accordingly. As an alternative, the cold ATES well could be relocated. Monitoring plan
Only temporary permit (e.g. 5 years)	Medium	Involve province, municipality and other stakeholders in early stage, agree on process and criteria for issuing of permits.
Additional monitoring prescriptions given by the competent authority resulting in higher costs and deteriorating the business case towards a No-Go	Medium	Involve province, municipality and other stakeholders in early stage, agree on process, criteria and key effects to monitor for issuing of permits Investigate manners of public funding of additional costs due to the demonstration and additional monitoring efforts.
Disturbance of subsurface chemistry and integrity	Medium	Careful impact assessment during design. Use certified contractors
More expensive permit procedure	Low	Involve province, municipality and other stakeholders in early stage, agree on process and criteria for issuing of permits.

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5.4. Conclusions policy and permit

The targeted reservoirs within this study do not reach deeper than 500 meters, which is within scope of the Water Law regime, with 'Gedeputeerde Staten' of the province as the competent authority. As the infiltration temperature exceeds 25 °C and the long-term heat surplus in the soil will occur HT-ATES does not fit standard ATES regulations. It is possible to deviate from these in case systems are implemented as a research project, which also account for HT-ATES projects. In order to make sure other interest are not harmed, the effects of the ATES system must be quantified by doing in an impact study. It can be concluded that provinces may grant licenses for HT-ATES pilot projects if no other interests are harmed.

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6. Conclusions & Recommendations

6.1. HT-ATES for TRIAS Westland

The technical and financial feasibility shows that there is potential to cost efficiently increase sustainable heat delivery from the geothermal wells of the TRIAS Westland site by applying an HT-ATES. The yearly total costs of the HT-ATES are considerably smaller than they would be if the same amount of heat would be delivered by gas fired boilers. The results of this feasibility study are summarised using the ULTIMATE KPI's in Table 15.

Table 15. overview of the ULTIMATE KPI's and the scales of the TRIAS Westland project.

Objective	How it will be measured/determined?	Scale: full-scale
HT Aquifer thermal energy storage and recovery	Heat recovery factor [-], Delivered heat cost [€/GJ], CO_2 reduction [t/a]	65 to 80 % 15 to 20 €/GJ 3 to 4 kton CO_2/y
Showing the success of the implemented circular economy systems	Substitution of fossil fuels by green energy [%]	5 to 6%*

*For the TRIAS Westland site, the heat storage and fossil substitution is 75-60 TJ. Because the system is very large (>1300 TJ) and has a high base-load heat demand, the contribution of HT-ATES to the total is limited. In other supply-demand conditions HT-ATES systems are more likely to facilitates 20 to 30% of the total heat demand.

Heat availability and demand

Due to the relatively high overall heat demand in the connected district heating network, there is a relatively limited (projected) reduction in heat demand in summer. Hence, heat available to store is limited, about 5% of the total amount of heat produced by the 2 geothermal doublets. Because the source of heat is quite large, the relative limited availability of heat in summer, still results in a considerable amount of heat, the potential amount of heat to be utilised in winter via storage with HT-ATES is 75-60 TJ/year for TRIAS Westland.

- *The amount of heat available in summer should be further analysed, to obtain better confidence in the amount of heat that can be stored over multiple years. This is important, because the performance of the HT-ATES and potential extra heat delivery depends on this. Given the large demand, additional sources of heat could also be considered.*
- *The exact concept for (hydraulic) integration should be further analysed to ensure the supply temperature will match production temperatures, and to maximise heat delivery from the HT-ATES.*

Subsurface

The deepest aquifer in Maassluis formation is very suitable for installation of HT-ATES wells. The top of the projected aquifer is at 210 m depth and the thickness is around 30m. The additional screening and logging proved to be key to identify available well

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screen depths. Exploratory simulations showed that the recovery efficiency of the 60 TJ storage capacity would be 65 to 80% depending on geological conditions.

- *The exact location of the HT-ATES wells is to be identified based on optimal integration in the district heating network and in coordination with the assessment of impact on other subsurface interests.*

Permitting
HT-ATES is allowed to be applied, however, no standard policy framework for permitting of these systems exists. The issuing of a permit requires a dedicated decision of the 'Gedeputeerde Staten' of the province.

- *If HT-ATES is further explored / elaborated, it is key to initiate contact with the province to coordinate the permitting procedure.*

6.2. Geothermal and HT-ATES for greenhouses

Requirement for seasonal storage
Greenhouses often exhibit a high base-load heat demand, resulting in limited heat availability in summer months for storage. Hence, the need for heat storage not always likely when greenhouses use geothermal heat. In the case of TRIAS Westland, the size of the heat source caused that with an availability of only ~5% of the total heat supply, still resulted in a reasonably large heat storage system of about 60-75 TJ. Given the high peak demand, there is potential for much more heat delivery when additional sources of heat are utilised, this would also increase the added value of the seasonal storage. The need and feasibility for heat storage will increase further when heat availability is the opposite of demand (e.g. solar).

Hence, the need for seasonal heat storage for greenhouses that use geothermal as a source for heat, strongly depends on the local conditions regarding the heat demand and supply profiles. Also the size of the source of heat relative to the total yearly demand affects to what extend heat storage has an added value.

Uncertainty reduction
Various HT-ATES feasibility studies have shown that prior detailed knowledge on the composition of the subsurface is key to correctly assess the feasibility. While drilling a geothermal well, the potential layers for HT-ATES are penetrated, which creates a window of opportunity to screen them to obtain this detailed insight. Logging/screening these shallow layers while targeting a (much) deeper aquifer, is a cost effective method to gather valuable information to reduce uncertainty for the application of HT-ATES.

In this study it was demonstrated that data acquisition for shallow layers during drilling activities for geothermal systems, can cost effectively and successfully be implemented. The obtained data provided great insight in potential layers at reasonable costs. The approach followed in this study could easily be used in other projects. This approach consisted of deepening the conductor drilling (usually around 100m depth) which in NL are generally made by smaller rigs. This has 2 main advantages:

1. The daily rate of such rigs is much lower than for the large rig drilling to several km depth.

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2. Such rigs allow for reverse circulation flush drilling, providing very accurate cutting samples along the borehole depth.

Discussion
In the case for TRIAS the smaller rig was possible to utilise, resulting in an additional cost of 30 k€ to get insights via cuttings, logging and cores. In case a small rig cannot be used the costs will be at least 2-3 times larger. In any case the costs are a small percentage (<<1%) of the total drilling costs needed for the geothermal doublet.

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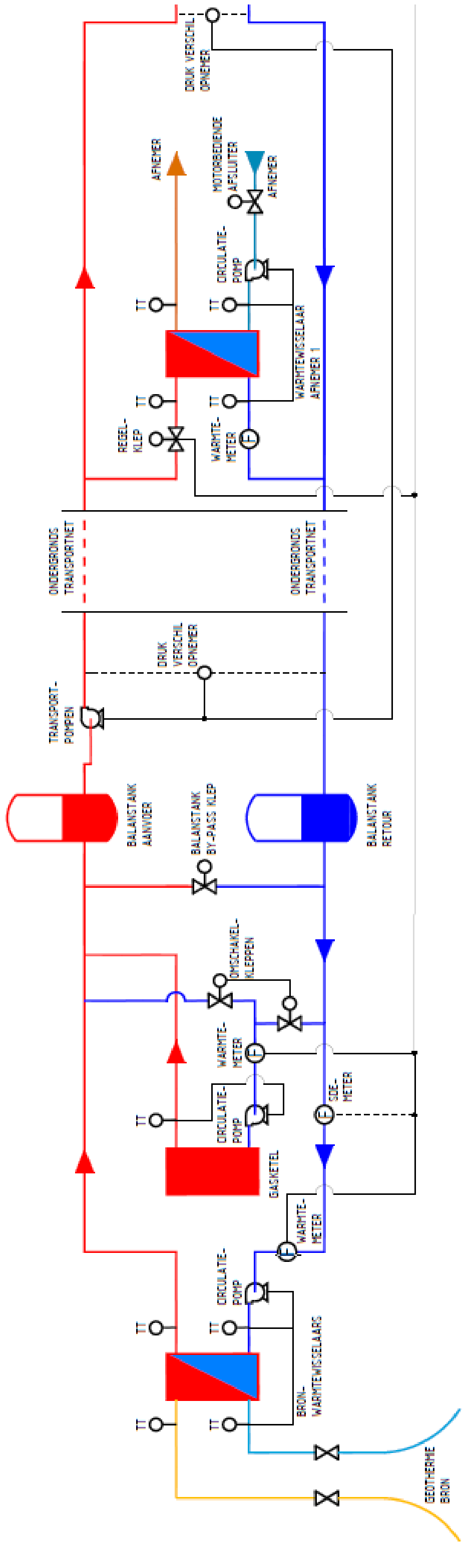
Appendix I. Heat supply system flow chart



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Appendix II. Drilling Maasdijk: plan for coring and logging [NL]

Van	Onderwerp	Datum
Stijn Beernink Martin Bloemendal	Dieper boren bij conductorboring Maasdijk: steekmonstername, logging en veiligstellen	15 december 2021
Bestemd voor	**Kopie / afschrift**	Pagina
Haitjema, HVC		45/67

Dieper boren bij conductor boring Maasdijk: steekmonstername, logging en veiligstellen

Aanleiding

De potentie van de ondergrond voor warmte opslag met Hoge Temperatuur Open-bodemenergie (HTO) bij het TRIAS Westland warmtenet dat door HVC wordt ontwikkeld wordt onderzocht als onderdeel van het ULTIMATE project door KWR. De potentie van HTO voor TRIAS blijkt groot te zijn uit een verkennende haalbaarheidsstudie. Verder is het aannemelijk dat HTO voor meerdere geothermieprojecten in het Westland een nuttige toevoeging kan zijn. Dus ook voor de bredere toepasbaarheid van geothermie en HTO in het Westland is het van belang om inzicht te hebben over de eigenschappen van potentieel geschikte lagen voor HTO.

De geschiktheid van de ondergrond voor HTO is in dit gebied echter nog onzeker. Het is bekend, o.b.v. van naburige boringen en regionale modellen, dat er watervoerende lagen bestaan in de Formatie van Maassluis, en in ook de Formatie van Oosterhout tussen een diepte van 150 tot 250 m -mv. Om de eigenschappen en dieptes van deze watervoerende lagen beter in kaart te brengen, en te bepalen of er goed afsluitende kleilagen aanwezig zijn wordt er een screening gedaan van deze lagen tussen 150 en 250 m-mv middels een proefboring. Tijdens deze proefboring worden cuttings verzameld, steekmonsters genomen en boorgatmetingen (logs) uitgevoerd.

Omdat in Maasdijk 6 boringen t.b.v. conductors van geothermiebronnen worden uitgevoerd tot 145 m-mv, wordt in 1 van deze boringen deze screening uitgevoerd als aanvullende werkzaamheid. In deze notitie staat beschreven wat deze aanvullende werkzaamheden inhouden.

Omschrijving boring

Haitjema, de aannemer van de conductor boringen, gaat in 1 van de geplaatste conductors (waarschijnlijk conductor nr. 4) van 145m -mv tot 275m -mv (130m) boren met een diameter van 300mm. Tijdens de boring wordt het opgeboorde materiaal beschreven volgens de richtlijnen in BRL11.000 en worden er een aantal steekmonsters genomen. Nadat het boorgat op diepte is en de boorstangen zijn uitgebouwd, zal Deltares boorgatmetingen uitvoeren.

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De stabiliteit van het boorgat, tijdens de boring, het uitvoeren van de steekmonsters en de logging, wordt gegarandeerd door overdruk in het boorgat middels een werkwater reservoir dat in verbinding staat met het boorgat, cf. de uitvoering van de conductor boringen.

Steekmonsers

Hier beschrijven we de procedure voor het nemen van de steekmonsters (hoeveel?, welke diepte?, o.b.v. welke kenmerken starten met steken?) en beschrijven we hoe de steekmonsters moeten worden gepreserveerd na steekmonstersname.

Methode en behandeling

Haitjema steekt monsters op de aangegeven diepte/momenten die beschreven staan in deze memo. De steekmonstername gebeurt in PVC-buizen van 1m lengte, 10cm diameter. Tijdens monstername wordt er zo goed mogelijk getracht om de monsters zo ongeschonden mogelijk uit de ondergrond te krijgen. Een optimale steekkern is volledig gevuld van boven- tot onderkant en is niet samengedrukt of gedeformeerd tijdens/na steekmonstername. Dit is belangrijk omdat er hydrogeologische en geotechnische metingen op de steekkernen zullen worden uitgevoerd in het lab.

Nadat de steekkern aan maaiveld is gebracht is het belangrijk dat de onderkant en bovenkant van de sample zo snel mogelijk luchtdicht wordt afgesloten om oxidatie en inmenging van andere grond/water te voorkomen en het behoudt van het oorspronkelijke grondwater te behouden. Dit kan gebeuren met 2 pvc deksel, die vervolgens worden vastgezet d.m.v. lijm en aanvullend een behandeling met vloeibaar plastic/parafine. Uiteindelijk worden de samples overgedragen aan KWR/TU Delft en worden de samples getransporteerd naar het lab in Delft.

Procedure monstername (diepte etc.)

O.b.v. de ingeschatte geohydrologische opbouw van de ondergrond hebben we een procedure vastgesteld wanneer steekmonsters genomen moeten worden. Het voornaamste doel van de steekmonsters is om het zandig materiaal te onderzoeken dat zich onder een laag klei bevindt. Op basis van Bijlage 1 zijn er een aantal te verwachtten kleilagen geïdentificeerd. In totaal gaan we minimaal 3 steekmonsters nemen:

1. Klei verwacht op ~170-180m -mv. Na het bereiken van het daar onderliggende zand ~180m diepte (1m continu zand): nemen steekmonster.
2. Klei verwacht op ~190-210m -mv. Na het bereiken van het daar onderliggende zand ~210m diepte (1m continu zand): nemen steekmonster.
3. Klei verwacht op ~230-240m -mv. Na het bereiken van het daar onderliggende zand ~240m diepte (1m continu zand): nemen steekmonster.

Indien er geen duidelijke kleilagen zichtbaar zijn tijdens de boring worden de steekmonsters genomen op een vastgestelde diepte van: 1. 185m -mv, 2. 215 m-mv en 3. 245 m-mv.

Voor het nemen van steekmonsters wordt door Haitjema in totaal 1 werkdag ingepland. Gedurende de boring wordt duidelijk hoeveel tijd het nemen van de steekmonsters inneemt. Indien de steekmonsters per monster minder tijd innemen zullen er 2 extra steekmonsters genomen worden, dus in totaal 5, afhankelijk van de beschikbare tijd.

Boorgatmetingen (logging)

Deltares voert boorgatmetingen uit in het open boorgat. De volgende metingen worden uitgevoerd:

- SONO/LONO (elektrische weerstand)
- Gamma Ray en Spectraal Gamma Ray
- Single Point Resistance (SPR)

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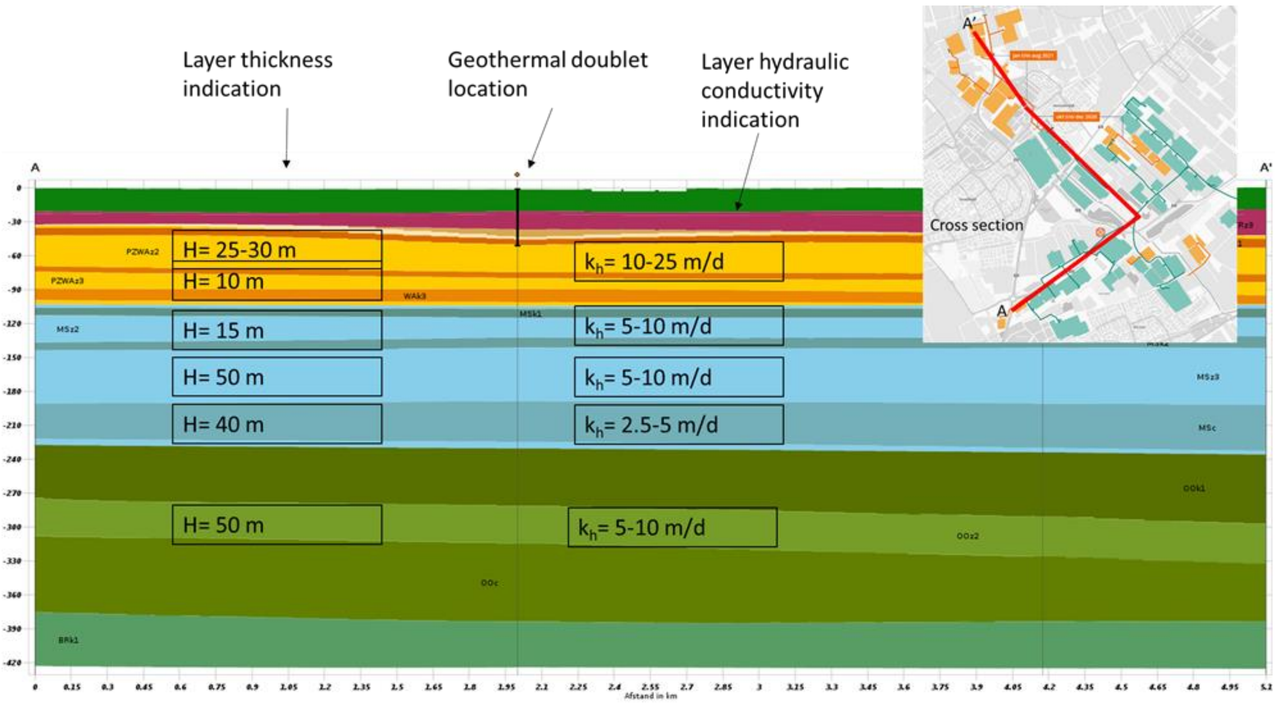
Deltares heeft 1 werkdag nodig om de werkzaamheden uit te voeren. Deltares rapporteert de uitkomsten als een briefrapport, en de data (.las) files worden gedeeld.

Aanvullen van het boorgat

Als de logging is uitgevoerd, wordt de het open geboorde traject (145-275 m-mv) weer aangevuld met aanvulgrind ter plaatse van zandlagen en kleikorrels ter plaatse van scheidende lagen, cf. BRL2.100.

Bijlage 1: beschrijving ondergrond

Een indicatieve beschrijving van de ondergrond is geproduceerd o.b.v het regionale REGIS model (Figuur 1). Hieruit blijkt dat er dieper dan 100m en ondieper 300m, 2 formaties zijn in de ondergrond met potentie voor HTO, de formatie van Maassluis en de formatie van Oosterhout. Echter, er zijn niet veel boringen die deze lagen beschrijven en dit model is dus gebaseerd op boringen op relatief grote afstand, er is dus een zekere mate van onzekerheid over de opbouw die is gegeven in Figuur 1.



Figuur 1 Lithologische opbouw in de ondergrond van het TRIAS Westland warmtenet volgens het regionale model REGIS. Blauw: formatie van Maassluis, groen: formatie van Oosterhout.

We kijken daarom ook naar andere, meer lokale, bronnen van informatie. In de database van NLOG zijn 3 boringen gevonden op relatief korte afstand van de boorlocatie en het TRIAS Westland warmtenetwerk (Figuur 2). Een relatief hoge GR duidt op de aanwezigheid van kleiig materiaal. We kunnen o.b.v. van deze datasets inschatten dat er kleiig ontwikkelde lagen aanwezig kunnen zijn op ~170-180m, ~190-210m, ~230-240m en ~265m. De rest van de ondergrond is waarschijnlijk voornamelijk zandig ontwikkeld.

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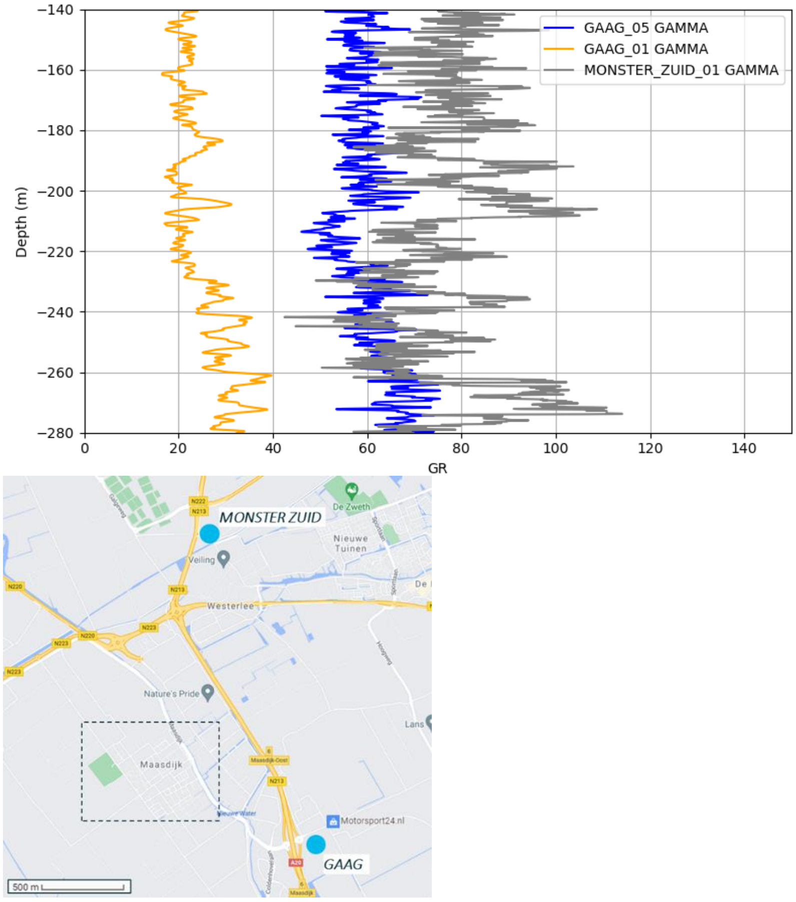

Figuur 2 Links: 3 GR datasets, afkomstig van naburige boringen, gepresenteerd voor het dieptedomein van 140 tot 280m diepte m-mv. Rechts: de locatie van de GR datasets t.o.v. de Maasdijk boorlocatie.

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Appendix III. Drilling Maasdijk: method and results

Methods

Additional screening was performed in combination with an already planned geothermal conductor drilling in Maasdijk in January-February 2022 (Figure 20). In Maasdijk, six conductors are currently being drilled for a geothermal project that is being developed. These conductors, steel casings that are used as the secured top part for the deep geothermal wells, are drilled to a depth of ~140m below surface level. The layer of most interest for HT-ATES are at a depth of 140 to 250m (the Maassluis formation). A 'deepening' drilling was designed and performed that used the existing conductor hole and extended the drilling below the depth of the casing.

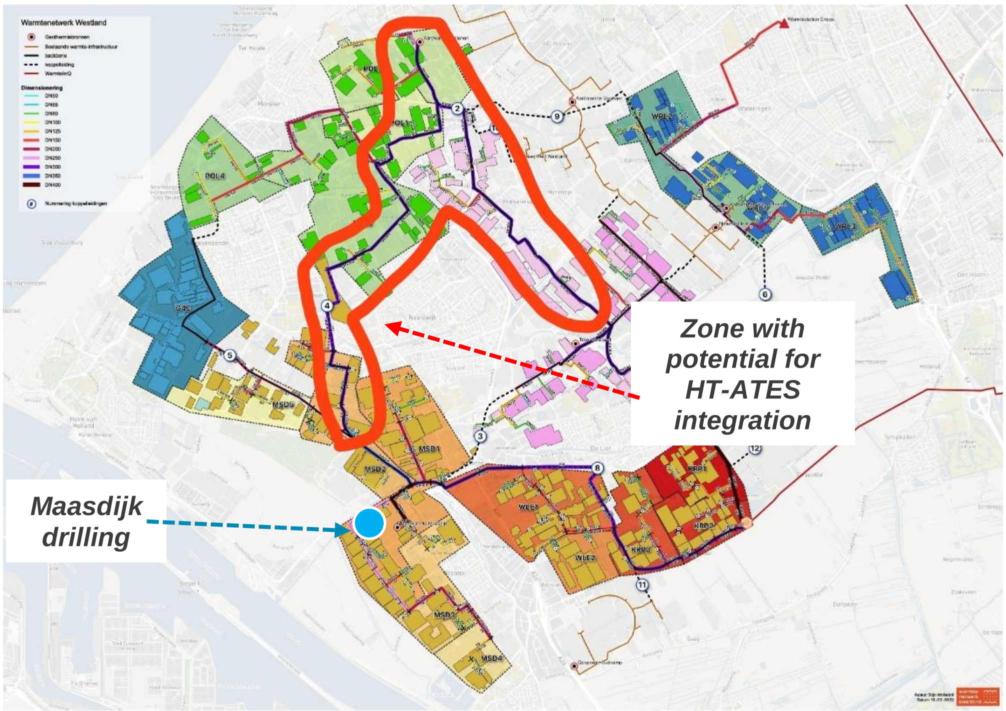

Figure 20 Overview of the district heating network. The red encircled zone is the preferred zone for integration of HT-ATES. The blue dot in the SW of the map is the location where additional hydrogeological data was acquired.

The deepening drilling was designed and performed in cooperation with HVC and Haitjema. The conductor casing was placed until 145m depth, the deepening drilling extended this borehole from ~145m depth to 275m depth with a 300m borehole diameter (Figure 21). The drilling activities were performed between January 24th – February 4th 2022. The (Dutch) note that was written for the activities is attached in appendix III. The following three activities have been carried out:

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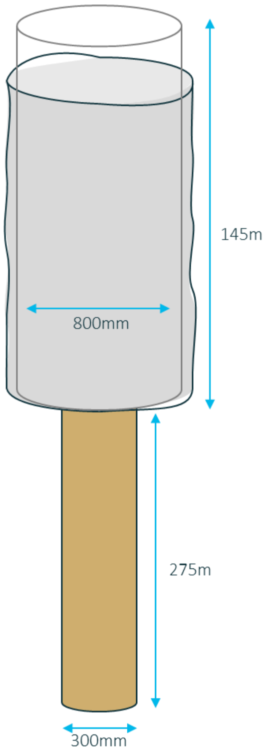

Figure 21 Simplified drawing of the deepening drilling.

1. Cutting sampling & description

During the drilling, cutting samples are taken each meter and stored in sample buckets. A subsample of the sediment per meter was collected in plastic bottles for lab analysis if needed later. After the completion of the deepening drilling, Haitjema described the properties of the cuttings following the BRL guidelines (attached in Appendix IV). With this description, an overview of the sediment-type and size per meter is given.

2. Core sampling

Core sampling is used to get an in-situ sample of the subsurface at a specific depth range. These samples provide insight in subsurface property variability and could be analyzed to determine important hydrogeological and thermal properties. The specific sampling depths were determined before the drilling based on available 'local' GR logging data of old oil drillings. The cores were taken using a coring technique that uses a load to hammer in the coring device (Figure 22). First, the coring device is dropped inside the borehole when the desired depth is reached. Secondly, the load, attached to the hinge of the drilling rig, is lowered inside the borehole. The hinge is continuously pulled an dropped for many times (e.g. >50) to push in de coring device. The process of hammering can take up to 30min.

After retrieval of the cores, the fullness of the PVC core is checked and if needed the core is cut to the filled size. As sound as possible, plastic end caps are put on the bottom and top to prevent oxygen mixing with the sediment and groundwater.

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Subsequently, the top and bottom of the core are filled with paraffin to seal off the sediment from the outside. Subsequently pvc endcaps are put on and taped. Finally, the depth, top/bottom marking and the name are applied on the core and end-caps using water-proof marker.

Figure 22 Picture of the coring device that was used to obtain the core samples. The left part is the cutting shoe that goes down into the borehole. The right (red) part is hammered with a weight to push it in the ground. When full, the red top is grabbed using the grabbing device (bottom) and subsequently hinged to the surface. To prevent the sediment from falling out, a check-valve is installed in the bottom of the coring device.

3. Geophysical logging

After the drilling on Friday the 28th of January, Deltares performed geophysical logging with 3 different logging probes (Table 16). The logging devices measure the average subsurface properties over the device length (1 – 2m) of the subsurface around the borehole. Gamma Ray (GR) is used to give indication of the clay content of the sediment. High relative GR means high clay content. With SONO (Short Normal electrical resistance measurement, 0.5m into subsurface) and LONO (Long Normal, 1.5m into subsurface) the electrical resistance of the soil+groundwater is measured. With fresh water, low resistance indicates high clay content and high resistance high sand content. With Single Point Resistance, the electrical resistance between the top and the bottom of the probe is measured. With sudden changes in SPR, sediment changes are indicated. With Electro Magnetic Induction (EM-induction), the bulk electrical conductivity of the subsurface is measured. Finally, also the spectral Gamma Ray (SGR) signal of the subsurface is measured. Like the normal Gamma Ray, high SGR measurements indicate high clay content, however, with SGR the three separate components of the GR signal (^{40}K, ^{232}Th, ^{238}U) are deduced. This could indicate the difference between high GR due to clay/sand and other material like glauconite.

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Table 16 Logging techniques performed by Deltares in the deepening drilling on Friday the 28th of January using 3 probes. The logging report is attached in Appendix V.

Nr	Manufacturer	Logging measurements
Probe 1	Antares	Gamma Ray, Short Normal, Long Normal, Single Point Resistance,
Probe 2	Century	Gamma Ray, EM-induction (IL)
Probe 3	Antares	Spectral Gamma Ray (^{40}K, ^{232}Th, ^{238}U)

Results

1. Cutting description

The results of the cuttings description by Haitjema is given in Appendix III. Based on this description, a general characterization of observed hydrogeological layering is produced in Table 17. Two major sandy layers are identified, one between 116 and 170m depth and the other between 220 and 257m depth. Besides this, also two more mixed (complex) layers are found that exist of a combination of heterogeneous clay, silt and sand layers.

Table 17 General characteristics of the Maassluis and Oosterhout (top part) formations. Gray colouring is used for clay layer, yellow colouring for a sand layer and no colouring for mixed layers.

Aquifer - name	Thickness (m)	Depth (m - sl)	Overall characteristic
3 – MSk1	12	104-116	Clay layer, mostly firm, also some shell fragments
3 – MSz2 / MSz3	54	116-170	Sandy layer, ranging from 180 to 260 µm, also sometimes small clay layers
3 – MSc	21	170-191	Mixed layer, sand and clay layers interspersed, on average 200 µm
4 – MSk2	15	191-206	Clay layer, mostly firm
4 – MSc	14	206-220	Sandy layer with thick shell layer at bottom
4 – MSz4 *(or OOz1?)*	37	220-257	Sandy layer, one 1m clay layer in between, average 200 µm
5 – OOk1	…	257-275	Clay layer, firm

2. Core samples

4 cores were taken in Maasdijk with a total length of 3.5m between185 to 246m below surface (Figure 23, Table 18).

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Figure 23 The 4 cores obtained from the deepening drilling in Maasdijk. Currently, these cores are stored in the TUD core fridge.

Table 18 the cores taken at the deepening drilling in Maasdijk in the Maassluis formation.

Core	Name	Depth (m - surface)
1	MSD1	185 - 186
2	MSD2	213 – 213.5 (half)
3	MSD3	214 - 215
4	MSD4	245 – 246

CT-scan analysis

To analyse the sediment cores without any form of destruction, the cores are scanned with a hospital CT-scanner (at the TU Delft rock-lab) using a resolution (voxel-size) of 0.23x0.23x0.6 mm (X,Y,Z). With CT-scanning, the density of material is measured on a non-dimensional CT density scale, ranging from air (~ -1000) to water (~0) to hard rock (>2000). As different sediments have different densities and different porosities, variability between sediments can be observed, in the range between 800 to 1400 density value. Also, CT-scanning is ideal to do a pre-assessment of quality and core dimensions without breakage of the sample (Figure 24). Here, the density values between -300 and +300 are highlighted red. This the volume with densities close to water and paraffin, as this has a slightly lower density than water.

Core sample 1 was only filled half in the PVC tube, the bottom is filled up with paraffin well, but the top part is unknown (Figure 24). The top part of core 2 is only filled partly and it is observed that the sediment was damaged in the coring process. Also here, the top part is covered with paraffin, the bottom seems to be only the pvc endcap. In core 3, the core seems full from the outside, but the CT-scan image shows that inside the core a big cavity exists filled with air that is originated because a part of the core broke loose from the top part. The top and bottom of the core are filled up nicely with paraffin. Core 4 is the most complete core, which shows more

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than 80cm of well filled core, including a thin paraffin layer on top and a big layer on the bottom of the core.

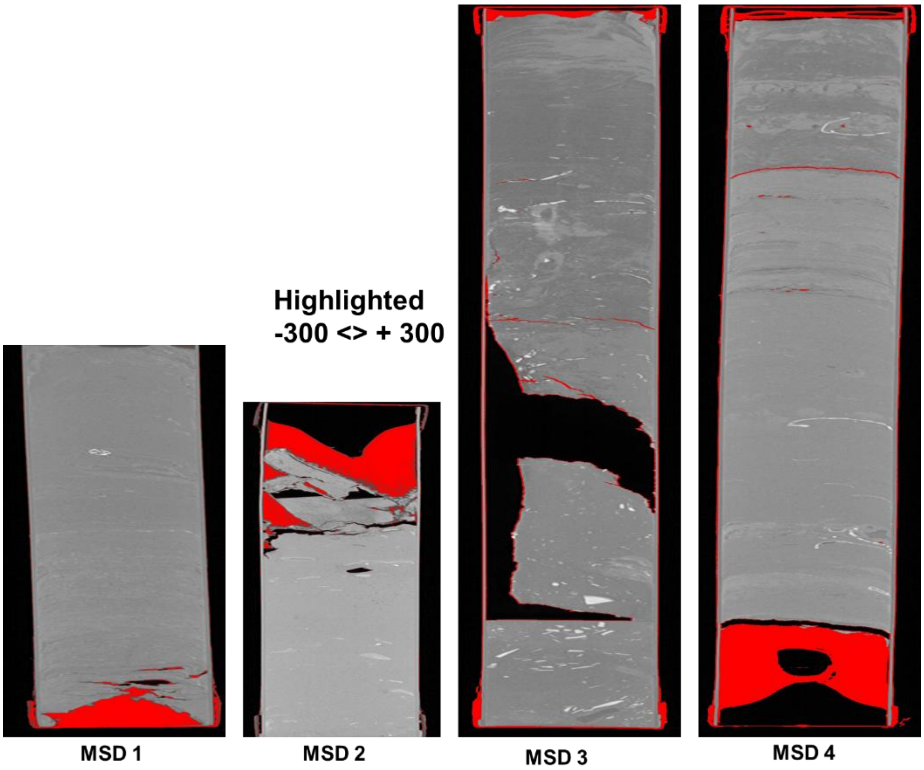

Figure 24 CT-scan with red highlight on zone with CT-scan value of -300 to 300, indicating the volume that is filled with density of water/paraffin. MSD1 was only half filled, empty top part is not scanned. Dark = low density, white = high density.

The sediment in the cores shows quite some vertical variability (Figure 25). Big shells, which were also reported from the cuttings, are clearly visible as the high density oddly shaped pieces in the matrix. Besides this, vertical layering is clearly observed, which could impact the hydrogeological characteristics of the Maassluis sands at these depths.

Lab analysis
Further analysis of the cores is currently being worked on. These are scheduled to be analyzed in the lab in Q4 2022. Aspects of interest are the horizontal and vertical hydraulic conductivity, thermal properties and geochemical characteristics.

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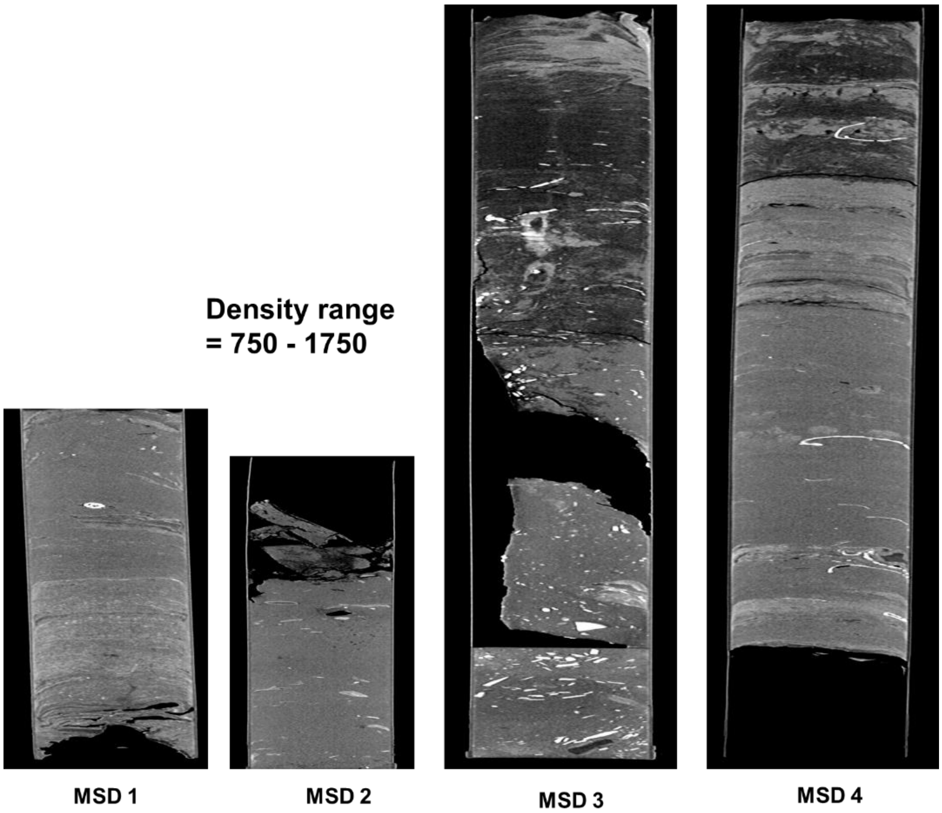

Figure 25 CT-scan with CT-scan value range between 750 and 1750, to maximize density difference between different sediment types. MSD1 was only half filled, empty top part is not scanned. Dark = low density, white = high density.

3. Logging interpretation

Here, the results of the logging campaign is shown. The most important objective is the identification of aquifers and aquitards. This lithological interpretation was done by Deltares based on the logging data, and the cuttings description (Figure 26). Two layers of medium grained sand are found, one at 145 to 175m depth and one at 210 to 245m depth.

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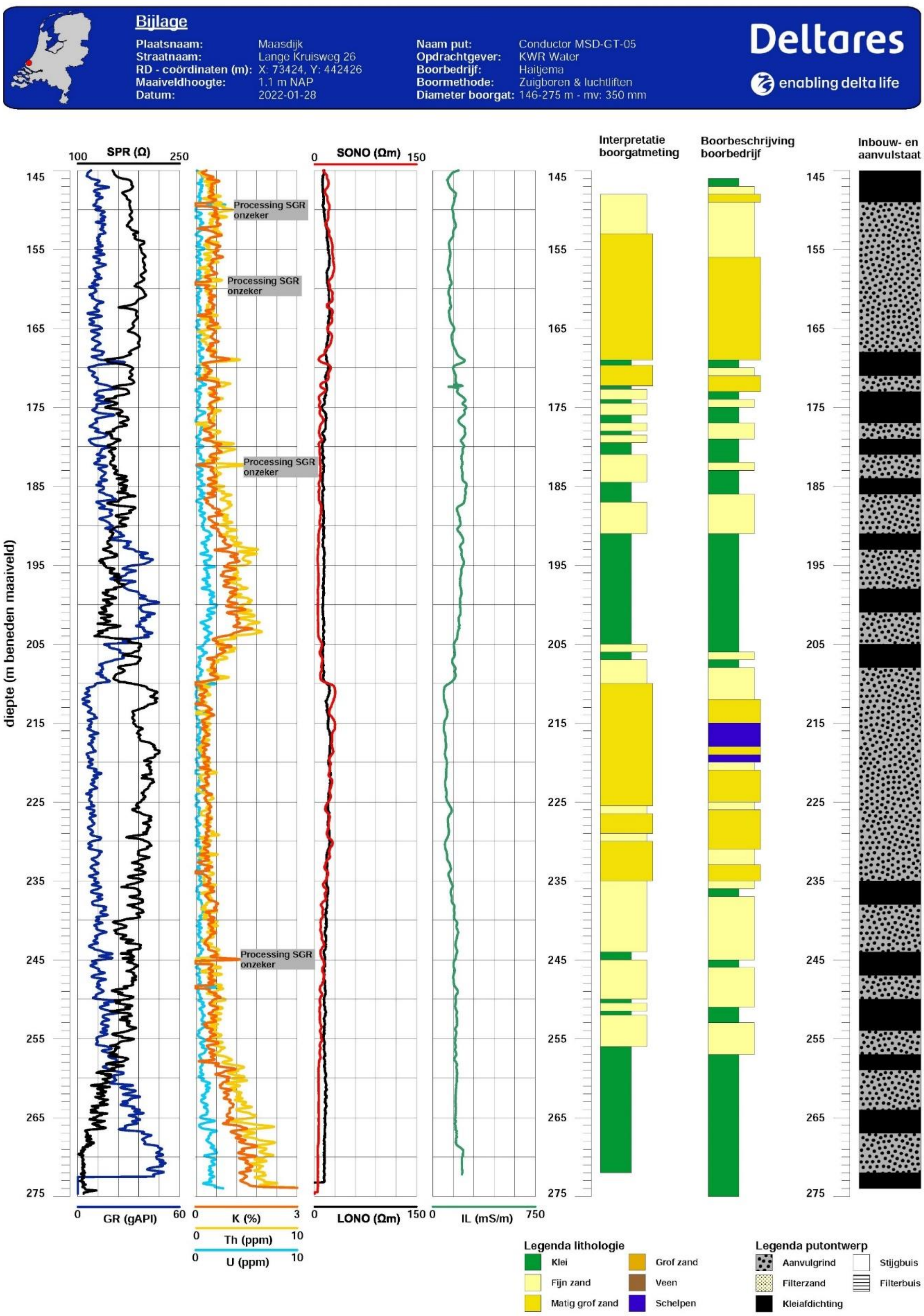

Figure 26 Lithological interpretation and well compeltion information from 145 to 275m depth, by Deltares based on the logging data and cuttings description.

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Appendix IV. Drilling Maasdijk: Cuttings description

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Boorprofiel
Conform BRL 2100

Boring	: **Conductor MSD-GT-05**	**Werkorder**	: **20210133 / 20210204**
Locatie	: MAASDIJK	Objectcode	: INDBRN00084
Projectnaam	: Aanbrengen van zes conductors	X / Y Coördinaten	: 73424,022 / 442426,254
Adres	: Lange Kruisweg 26	Maaiveld t.o.v. NAP	:
Uitvoeringsperiode	: 16-12 t/m 23-12-2021 / 24-1 t/m 31-1-2022	Boormeester	: H. Pouls / J.H. Dorman
		Einddiepte	: 275,00 m-m.v.
Boorsysteem	: Zuigboren/luchtliften	Boring beschreven	: 22-12-2021 / 27-1-2022
Diameter	: 750 / 350 mm	door projectleider	: M.K.V. van der Veen
Opdrachtgever	: HVC Groep / KWR Water Research Institute		

diepte in meters - maaiveld		omschrijving grondlagen volgens NEN 5104	M-waarde (µm)
0,00	1,00	ZAND, zeer grof, grijs/bruin, matig puinhoudend, sterk schelphoudend	300
1,00	2,00	ZAND, matig grof, buin/grijs, sterk schelphoudend	240
2,00	3,00	ZAND, matig fijn, donkergrijs, matig siltig, zwak schelphoudend	200
3,00	4,00	ZAND, zeer grof, donkergrijs, houtresten	300
4,00	5,00	ZAND, matig grof, donkergrijs, houtresten, kleibrokken	240
5,00	6,00	KLEI, slap, donkergrijs, sterk zandig, houtsporen	
6,00	7,00	ZAND, matig fijn, donkergrijs, houtresten, kleibrokjes	200
7,00	8,00	KLEI, slap, donkergrijs, houtresten, sterk zandig	
8,00	9,00	KLEI, slap, donkergrijs, houtresten, sterk zandig	
9,00	10,00	ZAND, matig fijn, donkergrijs, houtresten, kleibrokken	200
10,00	11,00	ZAND, matig fijn, donkergrijs, houtresten, kleibrokken	200
11,00	12,00	ZAND, matig grof, donkergrijs, houtresten, kleibrokken	220
12,00	13,00	ZAND, matig fijn, donkergrijs, houtresten, kleibrokken	200
13,00	14,00	ZAND, matig grof, donkergrijs, houtresten, kleibrokken	220
14,00	15,00	ZAND, matig grof, donkergrijs, houtresten	280
15,00	16,00	ZAND, matig grof, donkergrijs, houtresten	280
16,00	17,00	KLEI, slap, donkergrijs, zwak zandig	
17,00	18,00	KLEI, slap, donkergrijs, zwak zandig	
18,00	19,00	KLEI, slap, donkergrijs, sterk zandig	
19,00	20,00	KLEI, slap, donkergrijs, sterk zandig	
20,00	21,00	KLEI, matig vast, donkergrijs, zwak zandig	
21,00	22,00	KLEI, matig vast, donkergrijs, zwak zandig	
22,00	23,00	KLEI, slap, donkergrijs, matig zandig	
23,00	24,00	KLEI, slap, donkergrijs, matig zandig	
24,00	25,00	KLEI, slap, donkergrijs, matig zandig	
25,00	26,00	ZAND, matig fijn, donkergrijs	200
26,00	27,00	ZAND, matig grof, donkergrijs	260
27,00	28,00	ZAND, zeer grof, donkergrijs	320
28,00	29,00	ZAND, zeer grof, donkergrijs, enkele schelpen	340
29,00	30,00	ZAND, zeer grof, donkergrijs, enkele schelpen	320
30,00	31,00	ZAND, matig grof, donkergrijs, enkele schelpen	240
31,00	32,00	ZAND, matig grof, donkergrijs, enkele schelpen	280
32,00	33,00	ZAND, matig grof, donkergrijs, enkele schelpen	280
33,00	34,00	ZAND, matig grof, donkergrijs, enkele schelpen	260

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Boring	: **Conductor MSD-GT-05**	**Werkorder**	: **20210133 / 20210204**
Locatie	: MAASDIJK	Objectcode	: INDBRN00084
Projectnaam	: Aanbrengen van zes conductors		

diepte in meters - maaiveld		omschrijving grondlagen volgens NEN 5104	M-waarde (µm)
34,00	35,00	GRIND, lichtgrijs, zwak zandhoudend	
35,00	36,00	GRIND, lichtgrijs, zwak zandhoudend	
36,00	37,00	ZAND, zeer grof, lichtgrijs	340
37,00	38,00	ZAND, zeer grof, lichtgrijs	340
38,00	39,00	ZAND, matig fijn, lichtgrijs, kleibrokken	160
39,00	40,00	KLEI, vast, bruin/donkergrijs	
40,00	41,00	KLEI, vast, bruin/donkergrijs	
41,00	42,00	KLEI, vast, bruin/donkergrijs	
42,00	43,00	KLEI, vast, bruin/donkergrijs	
43,00	44,00	KLEI, vast, donkergrijs	
44,00	45,00	KLEI, vast, donkergrijs	
45,00	46,00	KLEI, vast, donkergrijs	
46,00	47,00	ZAND, matig grof, donkergrijs, houtsporen	220
47,00	48,00	ZAND, matig fijn, lichtgrijs	200
48,00	49,00	ZAND, matig fijn, lichtgrijs	200
49,00	50,00	ZAND, matig fijn, lichtgrijs	200
50,00	51,00	ZAND, matig grof, lichtgrijs	240
51,00	52,00	ZAND, matig grof, lichtgrijs	240
52,00	53,00	ZAND, matig grof, lichtgrijs, houtsporen	240
53,00	54,00	ZAND, matig fijn, lichtgrijs, houtsporen	200
54,00	55,00	ZAND, matig grof, lichtgrijs, houtsporen	240
55,00	56,00	ZAND, matig grof, lichtgrijs, houtresten, schelpenresten	260
56,00	57,00	ZAND, matig grof, lichtgrijs, houtsporen, schelenpresten	260
57,00	58,00	ZAND, matig grof, lichtgrijs, houtresten, enkele veenbrokjes	260
58,00	59,00	ZAND, matig grof, lichtgrijs, houtresten	260
59,00	60,00	ZAND, matig grof, lichtgrijs, houtresten	260
60,00	61,00	ZAND, matig fijn, donkergrijs, kleiig, verkitte klei	180
61,00	62,00	ZAND, matig fijn, donkergrijs, kleiig	180
62,00	63,00	ZAND, matig fijn, donkergrijs, houtsporen	200
63,00	64,00	KLEI, slap, donkergrijs	
64,00	65,00	KLEI, matig vast, donkergrijs	
65,00	66,00	KLEI, vast, donkergrijs, houtsporen	
66,00	67,00	KLEI, matig vast, donkergrijs	
67,00	68,00	KLEI, matig vast, donkergrijs, zwak zandig	
68,00	69,00	KLEI, matig vast, donkergrijs	
69,00	70,00	ZAND, matig fijn, donkergrijs, houtsporen	180
70,00	71,00	KLEI, matig vast, donkergrijs	
71,00	72,00	KLEI, matig vast, donkergrijs	
72,00	73,00	KLEI, matig vast, donkergrijs	
73,00	74,00	KLEI, matig vast, donkergrijs, matig zandig	
74,00	75,00	KLEI, slap, donkergrijs, sterk zandig	
75,00	76,00	ZAND, matig fijn, donkergrijs, kleibrokken	200

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Locatie	: MAASDIJK	Objectcode	: INDBRN00084
Projectnaam	: Aanbrengen van zes conductors		

diepte in meters - maaiveld		omschrijving grondlagen volgens NEN 5104	M-waarde (µm)
76,00	77,00	ZAND, matig fijn, donkergrijs	200
77,00	78,00	ZAND, matig grof, donkergrijs, houtsporen	220
78,00	79,00	ZAND, matig fijn, donkergrijs, houtsporen	180
79,00	80,00	ZAND, matig fijn, donkergrijs	200
80,00	81,00	ZAND, matig grof, donkergrijs	220
81,00	82,00	ZAND, matig grof, donkergrijs, houtsporen	220
82,00	83,00	ZAND, matig grof, donkergrijs, houtresten	220
83,00	84,00	KLEI, vast, donkergrijs, zwak zandig	
84,00	85,00	KLEI, vast, donkergrijs	
85,00	86,00	ZAND, matig fijn, donkergrijs, kleiig	200
86,00	87,00	ZAND, matig grof, donkergrijs	280
87,00	88,00	KLEI, vast, donkergrijs, zwak zandig	
88,00	89,00	KLEI, vast, donkergrijs	
89,00	90,00	KLEI, vast, donkergrijs	
90,00	91,00	KLEI, vast, donkergrijs	
91,00	92,00	ZAND, matig grof, donkergrijs	260
92,00	93,00	ZAND, matig grof, donkergrijs, houtsporen, kleibrokken	260
93,00	94,00	KLEI, matig vast, donkergrijs	
94,00	95,00	ZAND, matig grof, donkergrijs, zwak schelphoudend	280
95,00	96,00	ZAND, matig grof, donkergrijs, enkele kleibrokken	280
96,00	97,00	ZAND, matig grof, donkergrijs	280
97,00	98,00	ZAND, zeer grof, donkergrijs	300
98,00	99,00	ZAND, zeer grof, donkergrijs	300
99,00	100,00	ZAND, zeer grof, donkergrijs	300
100,00	101,00	ZAND, zeer grof, donkergrijs, matig schelphoudend	320
101,00	102,00	ZAND, zeer grof, donkergrijs, sterk schelphoudend, kleibrokken	300
102,00	103,00	ZAND, matig fijn, donkergrijs, houtsporen	200
103,00	104,00	ZAND, matig fijn, donkergrijs, kleibrokken	200
104,00	105,00	KLEI, matig vast, donkergrijs, sterk zandhoudend	
105,00	106,00	KLEI, matig vast, donkergrijs, sterk zandhoudend	
106,00	107,00	KLEI, matig vast, donkergrijs, sterk zandhoudend	
107,00	108,00	KLEI, vast, donkergrijs	
108,00	109,00	KLEI, vast, donkergrijs	
109,00	110,00	KLEI, vast, donkergrijs	
110,00	111,00	KLEI, vast, donkergrijs	
111,00	112,00	KLEI, vast, donkergrijs	
112,00	113,00	KLEI, vast, donkergrijs, zwak schelphoudend	
113,00	114,00	KLEI, vast, donkergrijs, zwak schelphoudend	
114,00	115,00	KLEI, vast, donkergrijs, zwak schelphoudend	
115,00	116,00	KLEI, vast, donkergrijs, zwak schelphoudend	
116,00	117,00	KLEI, vast, donkergrijs, matig schelphoudend	
117,00	118,00	ZAND, matig grof, donkergrijs, zwak schelphoudend, kleibrokken	240

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Locatie	: MAASDIJK	Objectcode	: INDBRN00084
Projectnaam	: Aanbrengen van zes conductors		

diepte in meters - maaiveld		omschrijving grondlagen volgens NEN 5104	M-waarde (µm)
118,00	119,00	ZAND, matig grof, donkergrijs, zwak schelphoudend, kleibrokken	240
119,00	120,00	SCHELPEN, lichtgrijs, sterk zandhoudend, kleibrokken	
120,00	121,00	ZAND, matig fijn, donkergrijs, kleiig	160
121,00	122,00	ZAND, matig fijn, donkergrijs, kleibrokken	200
122,00	123,00	ZAND, matig grof, donkergrijs	260
123,00	124,00	ZAND, matig grof, donkergrijs, zwak schelphoudend	220
124,00	125,00	ZAND, matig fijn, donkergrijs	200
125,00	126,00	ZAND, matig fijn, donkergrijs	180
126,00	127,00	ZAND, matig fijn, donkergrijs, kleiig	180
127,00	128,00	KLEI, matig vast, donkergrijs, zwak zandig	
128,00	129,00	KLEI, matig vast, donkergrijs, zwak zandig	
129,00	130,00	ZAND, matig fijn, donkergrijs, kleibrokken	200
130,00	131,00	ZAND, matig grof, donkergrijs, kleibrokken	220
131,00	132,00	ZAND, matig fijn, donkergrijs, kleibrokken	200
132,00	133,00	ZAND, matig fijn, donkergrijs, kleibrokken	200
133,00	134,00	ZAND, matig fijn, donkergrijs, kleibrokken	200
134,00	135,00	ZAND, matig grof, donkergrijs	260
135,00	136,00	ZAND, matig grof, donkergrijs	260
136,00	137,00	ZAND, matig grof, donkergrijs	260
137,00	138,00	ZAND, matig grof, donkergrijs, houtsporen	260
138,00	139,00	ZAND, matig grof, donkergrijs, houtsporen	240
139,00	140,00	ZAND, matig grof, donkergrijs	220
140,00	141,00	ZAND, matig fijn, donkergrijs, zwak schelphoudend	180
141,00	142,00	ZAND, matig grof, donkergrijs, zwak schelphoudend	240
142,00	143,00	ZAND, matig grof, donkergrijs, matig schelphoudend	220
143,00	144,00	ZAND, matig grof, donkergrijs, matig schelphoudend	240
144,00	145,00	ZAND, matig grof, donkergrijs, sterk schelphoudend	240
145,00	146,00	ZAND, matig grof, donkergrijs, sterk schelphoudend, enkele kleibrokken	220
		Dieper boren 24-1 t/m 31-1-2022	
146,00	147,00	CEMENT, kleibrokken	
147,00	148,00	ZAND, matig fijn, donkergrijs, kleibrokken	200
148,00	149,00	ZAND, matig grof, donkergrijs, zwak schelphoudend	220
149,00	150,00	ZAND, matig fijn, donkergrijs, enkele schelpresten	180
150,00	151,00	ZAND, matig fijn, donkergrijs, enkele schelpresten	200
151,00	152,00	ZAND, matig fijn, donkergrijs	180
152,00	153,00	ZAND, matig fijn, donkergrijs, houtsporen	180
153,00	154,00	ZAND, matig fijn, donkergrijs	180
154,00	155,00	ZAND, matig fijn, donkergrijs	200
155,00	156,00	ZAND, matig fijn, donkergrijs, houtsporen	200
156,00	157,00	ZAND, matig grof, donkergrijs	220
157,00	158,00	ZAND, matig grof, donkergrijs	220
158,00	159,00	ZAND, matig grof, donkergrijs	220
159,00	160,00	ZAND, matig grof, donkergrijs	220

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Boring	: **Conductor MSD-GT-05**	**Werkorder**	: **20210133 / 20210204**
Locatie	: MAASDIJK	Objectcode	: INDBRN00084
Projectnaam	: Aanbrengen van zes conductors		

diepte in meters - maaiveld		omschrijving grondlagen volgens NEN 5104	M-waarde (μm)
160,00	161,00	ZAND, matig grof, donkergrijs, zwak schelphoudend, enkele stenen	260
161,00	162,00	ZAND, matig grof, donkergrijs, zwak schelphoudend	240
162,00	163,00	ZAND, matig grof, donkergrijs, enkele schelp	240
163,00	164,00	ZAND, matig grof, donkergrijs, enkele schelp	240
164,00	165,00	ZAND, matig grof, donkergrijs, zwak schelphoudend	240
165,00	166,00	ZAND, matig grof, donkergrijs, zwak schelphoudend	240
166,00	167,00	ZAND, matig grof, donkergrijs, enkel kleibrokje, houtsporen	240
167,00	168,00	ZAND, matig grof, donkergrijs, enkel kleibrokje, houtsporen	240
168,00	169,00	ZAND, matig grof, donkergrijs, enkel kleibrokje, houtsporen	240
169,00	170,00	KLEI, matig vast, donkergrijs, zwak zandig	
170,00	171,00	ZAND, matig fijn, donkergrijs, enkele kleibrok, houtsporen	200
171,00	172,00	ZAND, matig grof, donkergrijs, enkele schelp	280
172,00	173,00	ZAND, matig grof, donkergrijs, matig schelphoudend	280
173,00	174,00	KLEI, matig vast, donkergrijs, zwak zandig	
174,00	175,00	ZAND, matig fijn, donkergrijs, matig kleiig	200
175,00	176,00	KLEI, matig vast, donkergrijs, zwak zandig	
176,00	177,00	KLEI, matig vast, donkergrijs, zwak zandig	
177,00	178,00	ZAND, matig fijn, donkergrijs, kleibrokjes	180
178,00	179,00	ZAND, matig fijn, donkergrijs, kleibrokjes	180
179,00	180,00	KLEI, matig vast, donkergrijs, zwak zandig	
180,00	181,00	KLEI, matig vast, donkergrijs	
181,00	182,00	KLEI, matig vast, donkergrijs	
182,00	183,00	ZAND, matig fijn, donkergrijs, matig kleiig	180
183,00	184,00	KLEI, slap, donkergrijs, sterk zandig	
184,00	185,00	KLEI, slap, donkergrijs, sterk zandig	
185,00	186,00	KLEI, slap, donkergrijs, sterk zandig	
186,00	187,00	ZAND, matig fijn, donkergrijs, sterk kleiig	180
187,00	188,00	ZAND, matig fijn, donkergrijs, sterk kleiig	180
188,00	189,00	ZAND, matig fijn, donkergrijs, verkitte klei	200
189,00	190,00	ZAND, matig fijn, donkergrijs, zwak kleiig	200
190,00	191,00	ZAND, matig fijn, donkergrijs, zwak kleiig, enkele schelpresten	180
191,00	192,00	KLEI, matig vast, donkergrijs, verkitte klei	
192,00	193,00	KLEI, matig vast, donkergrijs, enkele schelpresten	
193,00	194,00	KLEI, vast, donkergrijs	
194,00	195,00	KLEI, vast, donkergrijs	
195,00	196,00	KLEI, vast, donkergrijs	
196,00	197,00	KLEI, vast, donkergrijs	
197,00	198,00	KLEI, vast, donkergrijs	
198,00	199,00	KLEI, vast, donkergrijs	
199,00	200,00	KLEI, vast, donkergrijs	
200,00	201,00	KLEI, vast, donkergrijs	
201,00	202,00	KLEI, vast, donkergrijs	
202,00	203,00	KLEI, vast, donkergrijs	
203,00	204,00	KLEI, vast, donkergrijs	
204,00	205,00	KLEI, vast, donkergrijs	

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Grondboorbedrijf Haitjema B.V.

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Boring	: **Conductor MSD-GT-05**	**Werkorder**	: **20210133 / 20210204**
Locatie	: MAASDIJK	Objectcode	: INDBRN00084
Projectnaam	: Aanbrengen van zes conductors		

diepte in meters - maaiveld		omschrijving grondlagen volgens NEN 5104	M-waarde (µm)
205,00	206,00	KLEI, matig vast, donkergrijs, zwak zandig	
206,00	207,00	ZAND, matig fijn, donkergrijs, matig kleiig	180
207,00	208,00	KLEI, slap, donkergrijs	
208,00	209,00	ZAND, matig fijn, donkergrijs, enkele schelpresten, kleibrokjes	180
209,00	210,00	ZAND, matig fijn, donkergrijs, sterk kleiig, zwak schelphoudend	180
210,00	211,00	ZAND, matig fijn, donkergrijs, sterk kleiig, zwak schelphoudend	180
211,00	212,00	ZAND, matig fijn, donkergrijs, sterk schelphoudend	200
212,00	213,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
213,00	214,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
214,00	215,00	ZAND, matig grof, donkergrijs, sterk schelphoudend	240
215,00	216,00	SCHELPEN	
216,00	217,00	SCHELPEN	
217,00	218,00	SCHELPEN, zwak zandig	
218,00	219,00	ZAND, matig grof, donkergrijs, sterk schelphoudend	260
219,00	220,00	SCHELPEN, sterk zandhoudend	
220,00	221,00	ZAND, matig fijn, donkergrijs, zwak schelphoudend	200
221,00	222,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
222,00	223,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
223,00	224,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
224,00	225,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
225,00	226,00	ZAND, matig fijn, donkergrijs, enkele schelpen, zwak kleiig	200
226,00	227,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
227,00	228,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
228,00	229,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
229,00	230,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
230,00	231,00	ZAND, matig grof, donkergrijs, enkele schelpen	220
231,00	232,00	ZAND, matig fijn, donkergrijs, enkele schelpen, enkele kleibrokjes	200
232,00	233,00	ZAND, matig fijn, donkergrijs, enkele schelpen, enkele kleibrokjes	200
233,00	234,00	ZAND, matig grof, donkergrijs, enkele schelpen, enkele kleibrokjes	220
234,00	235,00	ZAND, matig grof, donkergrijs, enkele schelpen, enkele kleibrokjes	220
235,00	236,00	ZAND, matig fijn, donkergrijs, enkele schelpen, enkele kleibrokjes	200
236,00	237,00	KLEI, vast, donkergrijs, zwak zandig	
237,00	238,00	ZAND, matig fijn, donkergrijs, enkele schelpen	200
238,00	239,00	ZAND, matig fijn, donkergrijs, enkele schelpen	200
239,00	240,00	ZAND, matig fijn, donkergrijs, enkele schelpen, kleibrokjes	180
240,00	241,00	ZAND, matig fijn, donkergrijs, sterk kleiig	160
241,00	242,00	ZAND, matig fijn, donkergrijs, sterk kleiig, enkele schelpen	180
242,00	243,00	ZAND, matig fijn, donkergrijs, sterk kleiig, enkele schelpen	180
243,00	244,00	ZAND, matig fijn, donkergrijs, kleibrokken	180
244,00	245,00	ZAND, matig fijn, donkergrijs, matig kleiig	180
245,00	246,00	KLEI, slap, donkergrijs, matig zandig	
246,00	247,00	ZAND, matig fijn, donkergrijs, kleibrokken	180
247,00	248,00	ZAND, matig fijn, donkergrijs, kleibrokken, enkele schelpen	180
248,00	249,00	ZAND, matig fijn, donkergrijs, kleibrokken, enkele schelpen	180
249,00	250,00	ZAND, matig fijn, donkergrijs, kleibrokken, enkele schelpen	180

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haitjema grondwatertechniek

Boring	: **Conductor MSD-GT-05**	**Werkorder**	: **20210133 / 20210204**
Locatie	: MAASDIJK	Objectcode	: INDBRN00084
Projectnaam	: Aanbrengen van zes conductors		

diepte in meters - maaiveld		omschrijving grondlagen volgens NEN 5104	M-waarde (µm)
250,00	251,00	ZAND, matig fijn, donkergrijs, kleibrokken	180
251,00	252,00	KLEI, matig vast, donkergrijs, enkele schelpen	
252,00	253,00	KLEI, matig vast, donkergrijs, enkele schelpen	
253,00	254,00	ZAND, matig fijn, donkergrijs, zwak kleiig	180
254,00	255,00	ZAND, matig fijn, donkergrijs, zwak kleiig	180
255,00	256,00	ZAND, matig fijn, donkergrijs	200
256,00	257,00	ZAND, matig fijn, donkergrijs, zwak schelphoudend	200
257,00	258,00	KLEI, vast, donkergrijs, zwak zandhoudend	
258,00	259,00	KLEI, vast, donkergrijs	
259,00	260,00	KLEI, vast, donkergrijs	
260,00	261,00	KLEI, vast, donkergrijs	
261,00	262,00	KLEI, vast, donkergrijs	
262,00	263,00	KLEI, vast, donkergrijs, enkele schelpen	
263,00	264,00	KLEI, vast, donkergrijs	
264,00	265,00	KLEI, vast, donkergrijs	
265,00	266,00	KLEI, vast, donkergrijs, enkele schelpen	
266,00	267,00	KLEI, vast, donkergrijs	
267,00	268,00	KLEI, vast, donkergrijs	
268,00	269,00	KLEI, vast, donkergrijs	
269,00	270,00	KLEI, vast, donkergrijs	
270,00	271,00	KLEI, vast, donkergrijs	
271,00	272,00	KLEI, vast, donkergrijs	
272,00	273,00	KLEI, vast, donkergrijs	
273,00	274,00	KLEI, vast, donkergrijs	
274,00	275,00	KLEI, vast, donkergrijs	
		Er zijn 3 steekmonsters genomen:	
		1: 185,00-186,00 m-m.v.	
		2: 214,00-215,00 m-m.v.	
		3: 245,00-246,00 m-m.v.	
		28-1-2022 Boorgatmeting Deltares	

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Appendix V. Drilling Maasdijk: Logging report [NL]

Deltares

Grondboorbedrijf Haitjema B.V.
T.a.v. de heer M. van der Veen
Wisseling 10
7701 GS DEDEMSVAART

Datum	Ons kenmerk		Aantal pagina's
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Contactpersoon	**Doorkiesnummer**	**E-mail**	
Pieter Pauw	+31(0)88 335 7868	Pieter.Pauw@deltares.nl	

Onderwerp
Uitwerking boorgatmetingen Conductor MSD-GT-05 Maasdijk

Geachte heer Van der Veen,

Op 28 januari 2022 heeft Deltares drie boorgatmetingen uitgevoerd nabij de Lange Kruisweg 26 in Maasdijk (zie onze offerte van 26 november 2021). De metingen vonden plaats in het open boorgat van 146-275 m beneden maaiveld (mv) en een boordiameter van 350 mm. In de bovenste 146 m bevond zich een stalen casing. Het doel van de metingen was om extra informatie over de ondergrond te verzamelen. Het boorgat heeft als kenmerk Conductor MSD-GT-05 en heeft de volgende Rijksdriehoek coördinaten: X: 73424 m, Y: 442426 m.

Methode
Voor de boorgatmetingen zijn drie sondes gebruikt. Met een sonde van de Duitse fabrikant Antares zijn de volgende metingen verricht:

- Gamma (*GR; Gamma Ray*) meting. Met deze meting wordt de natuurlijke gammastraling van de ondergrond gemeten. Klei zendt over het algemeen meer gammastraling uit dan zand. Voor de *GR* resultaten is de gestandaardiseerde eenheid gAPI (gamma-ray American Petroleum Industry) gehanteerd. Een hoge gAPI waarde duidt op de aanwezigheid van klei, een lage gAPI waarde duidt op zand. Aanvulklei en het mineraal glauconiet hebben doorgaans ook invloed op de *GR* waarden.
- Short Normal (*SONO*) meting. Met een SONO meting wordt de elektrische weerstand (eenheid Ωm) van een beperkte zone (~0.5 m) rondom de sonde gemeten. De gemeten elektrische weerstand hangt af van de boorvloeistof, de diameter van het boorgat, het grondwater en de geologische formatie. Bij een open boorgat met zoet grondwater, duidt een relatief lage elektrische weerstand op de aanwezigheid van klei. Bij een open boorgat met zoet grondwater, duidt een relatief hoge elektrische weerstand op de aanwezigheid van zand. In zout grondwater is dit onderscheid vaak minder goed te maken.

enabling delta life

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Deltares is ingeschreven in het handelsregister van de Kamer van Koophandel Haaglanden onder nummer 41146461 als Stichting Deltares

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- Long Normal (*LONO*) meting. De LONO meting is analoog aan de SONO meting, behalve dat bij een LONO meting een groter bereik rondom de sonde wordt meegenomen, waardoor er dieper (~1.5 m) in de geologische formatie wordt gemeten.
- Single Point Resistance (*SPR*) meting. Bij een SPR meting wordt de elektrische weerstand tussen de bovenkant en de onderkant van de sonde gemeten. De gemeten elektrische weerstand kan alleen kwalitatief worden gebruikt. Bij lithologie-overgangen is vaak een anomalie in de SPR waarden te zien.

Voor de elektromagnetische (EM)-Inductie meting is sonde (9511A) van het Amerikaanse bedrijf Century gebruikt. Met deze sonde zijn de volgende metingen verricht:

- Gamma (*GR; Gamma Ray*) meting (zie omschrijving bij de Antares zonde).
- EM-inductie meting (*IL*). In een spoel in de sonde wordt een primair EM veld opgewekt. Door geleiding in de ondergrond induceert het primaire EM veld een secundair EM veld, dat in amplitude en fase verschilt van het primaire veld. Beiden velden worden gemeten in een ontvangerspoel. Aan de hand van de verschillen in het primaire en secundaire veld in de ontvangerspoel kan de elektrische geleidbaarheid van de ondergrond (EC_{bulk}) worden afgeleid. In de uitwerking is EC_{bulk} weergegeven als COND.

De spectraalgamma meting is verricht met een sonde van het Duitse bedrijf Antares. Met deze meting wordt de natuurlijke gammastraling van de ondergrond gemeten. Deze gammastraling komt vrij bij natuurlijk radioactief verval van de radio-isotopen ^{40}K (Kalium), ^{232}Th (Thorium) en ^{238}U (Uranium). In klei komt over het algemeen meer gammastraling vrij dan in zand. Ook de aanwezigheid van het mineraal glauconiet draagt met de aanwezigheid van ^{40}K in veel gevallen bij aan de gammastraling.

De spectraal gamma sonde bevat een detector die de binnenkomende gammastraling omzet in lichtpulsen. De intensiteit van het licht is gelijk aan de energie van de gammastraling. Omdat deze energie verschilt tussen ^{40}K, ^{232}Th en ^{238}U kan aan de hand van het energiespectrum van de binnenkomende gammastraling de bijdragen van de afzonderlijke isotopen worden bepaald.

Onjuiste interpretaties van het spectrum kunnen voorkomen bij incorrecte 'picking' van de ^{40}K, ^{232}Th en ^{238}U pieken. In de bijlage is aangegeven waar incorrecte picking mogelijk heeft plaatsgevonden.

Resultaten

Weergave boorbeschrijving en lithologische interpretatie van de boorgatmetingen

In de bijlage zijn de resultaten van de metingen, de lithologische interpretatie van de boorgatmeting, de boorbeschrijving en de aanvulstaat tezamen weergegeven. Voor de lithologische interpretatie van de boorgatmeting maken wij normaliter gebruik van de lithoklassen 'veen', 'klei', 'fijn zand', 'matig grof zand' en 'grof zand'. Om een goede vergelijking mogelijk te maken is deze indeling ook gebruikt voor het weergeven van de boorbeschrijving van het boorbedrijf. Hierbij dient het volgende te worden opgemerkt:

- De lithoklasse 'Zand, matig grof' in de boorbeschrijving van het boorbedrijf is weergegeven als 'matig grof zand'.
- De lithoklasse 'Schelpen' is niet in de interpretatie van de boorgatmeting gebruik. Het onderscheidend vermogen is daarvoor onvoldoende.
- De lithoklasse 'Zand, matig fijn' in de boorbeschrijving van het boorbedrijf is weergegeven als 'Fijn zand'.

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- De lithoklasse 'Schelpen' is niet gebruikt voor de lithologische interpretatie van de boorgatmeting.
- De lithoklassen 'Veen' en 'Grof zand' komen niet voor in het traject.
- De kleur, de M50, de textuur en de bijmenging (bijvoorbeeld van klei, steenkool, zandsteen of kalksteen) in de boorbeschrijving van het boorbedrijf zijn niet weergegeven in de bijlage.

In de uitwerking van de aanvulstaat is Mikolit 300 aangegeven als 'kleiafdichting'.

Lithologische en hydrogeologische interpretatie van de resultaten

De ondergrond bestaat van 145 tot ongeveer 170 m -mv uit fijn tot matig grof zand, behorend tot de formatie van Maassluis. Daaronder treffen we een heterogene, klei-rijke sectie aan tot ~205 m -mv. Het onderste deel van deze sectie is kleiiger dan bovenste deel, waar we meer fijn zand vinden. De eenheid fungeert waarschijnlijk als scheidende laag en behoort ook tot de formatie van Maassluis.

Vanaf ongeveer 205-210 m -mv nemen de GR en COND waarden af en lopen de SONO en LONO waarden op; dit markeert de overgang naar een watervoerend pakket bestaande uit voornamelijk fijn tot matig grof zand. De basis van dit watervoerende pakket bevindt zich op ongeveer 255 m -mv. Bovenin (tot ~235 m -mv) is het sediment grover en schelprijker dan onderin, waar we meer klei aantreffen. Dit watervoerende pakket kan (voornamelijk) tot de formatie van Oosterhout gerekend worden. Aan de basis vinden we een kleilaag. Hier zijn de GR waarden duidelijk hoger dan daarboven.

De COND resultaten duiden op brak tot zout grondwater van 145-275 m -mv.

Nadere Informatie

Dit briefrapport is opgesteld door Pieter Pauw. Bij vragen kunt u contact met hem opnemen. De review is verricht door Pieter Doornenbal.

Hoogachtend,

Maaike Blauw
Afdelingshoofd Toegepaste geologie en geofysica
Unit Bodem- en Grondwatersystemen

Bijlage(n)
1

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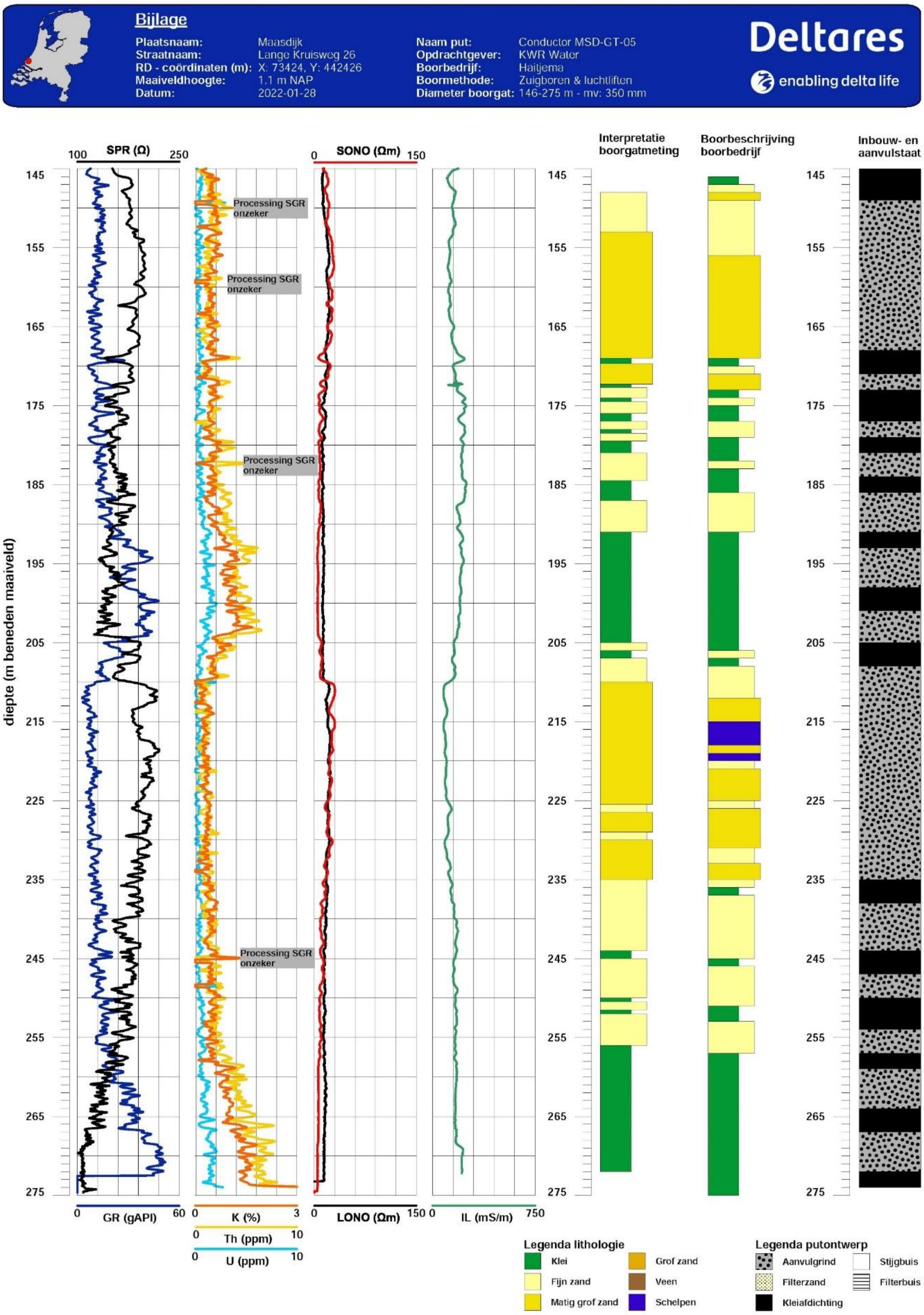

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